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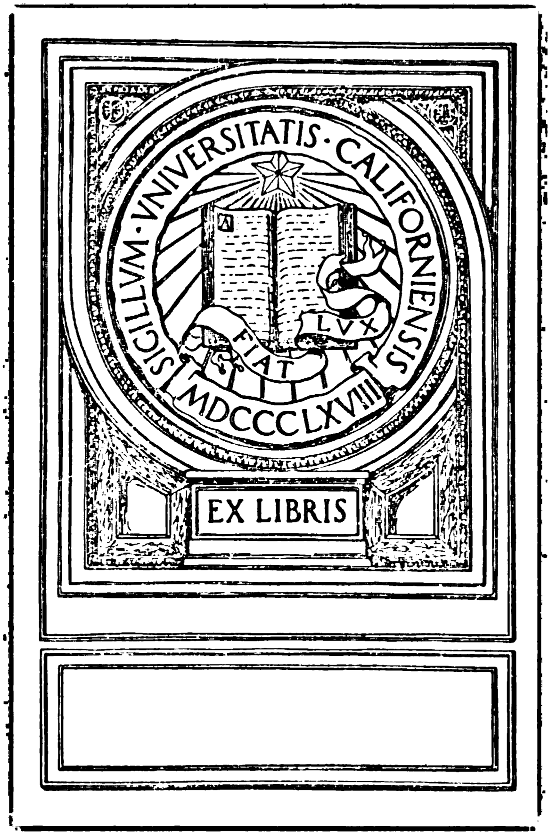
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54TH CONGRESS, } HOUSE OF REPRESENTATIVES. { DOCUMENT
1st Session. } { No. 279.

NICARAGUA CANAL.

MESSAGE

FROM THE

PRESIDENT OF THE UNITED STATES,

TRANSMITTING

THE REPORT OF THE BOARD OF ENGINEERS FOR THE PURPOSE OF
ASCERTAINING THE FEASIBILITY, PERMANENCE, AND COST OF
CONSTRUCTION AND COMPLETION OF THE NICARAGUA
CANAL BY THE ROUTE CONTEMPLATED AND PRO-
VIDED FOR BY THE ACT WHICH PASSED
THE SENATE JANUARY 28, 1895.

OF THE
UNIVERSITY
OF

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1896.

TC [illegible]
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54TH CONGRESS, 1st Session. } HOUSE OF REPRESENTATIVES. { DOCUMENT No. 279.

NICARAGUA CANAL.

OF

MESSAGE

FROM THE

PRESIDENT OF THE UNITED STATES,

TRANSMITTING

The report of the Board of Engineers for the purpose of ascertaining the feasibility, permanence, and cost of construction and completion of the Nicaragua Canal by the route contemplated and provided for by the act which passed the Senate January 28, 1895.

FEBRUARY 7, 1896.—Referred to the Committee on Interstate and Foreign Commerce,
MARCH 4, 1896.—Ordered to be printed.

To the House of Representatives:

Pursuant to the request made in a House resolution passed on the 30th day of January, 1896, I herewith transmit the report, with accompanying maps and exhibits, of the Board of Engineers under the provisions of chapter 189, of laws of 1895, for the purpose of ascertaining the feasibility, permanence, and cost of the construction and completion of the Nicaragua Canal by the route contemplated and provided for by the act which passed the Senate January 28, 1895, entitled "An act to amend an act entitled 'An act to incorporate the Maritime Canal Company of Nicaragua,' approved February 20, 1889."

GROVER CLEVELAND.

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REPORT

OF THE

NICARAGUA CANAL BOARD.

5

LETTER OF TRANSMITTAL.

NICARAGUA CANAL BOARD,
New York, October 31, 1895.

The PRESIDENT.
(Through the State Department):

The Board of Engineers appointed pursuant to a provision in the act of Congress approved March 2, 1895, has the honor to submit herewith its report, accompanied by appendixes and maps, illustrative of the major features of the Nicaragua Canal project.

The act required personal inspection by the Board of the route of the canal. This was made in the months of May and June, and the Board desires to express its obligations to the honorable the Secretary of the Navy for the use of the U. S. S. *Montgomery* as a means of transportation to and from Nicaragua, Costa Rica, and Colombia, as well as for authorizing the detail of a naval medical officer to accompany and attend the Board and its party, and to the commanding and other officers of the *Montgomery* for continuing courtesies.

The survey of the anchorage and approaches to Greytown Harbor, made under the direction of Commander Davis, by Lieutenant Lyman and his associates, has been of great value to the Board in preparing its report.

Sailing from Mobile May 7, and arriving at Greytown, Nicaragua, May 13, the Board was received at the wharf by United States Consul O'Hara, by the comandante, General Rivas, and by two commissioners, Don Maximiliano Sonnenstern and Mr. Julius Wiest, representing the minister of public works, with instructions to aid and cooperate with the Board in its investigations.

Throughout Nicaragua the Board was received with marked attention by the State officials, was given a special audience by the President and his cabinet at Managua May 28, and was granted the free use of the State telegraph and of the Government vessel on Lake Nicaragua.

At Greytown the Board made a full and careful examination of the entire locality, surveyed the shore lines preliminary to the hydrographic survey by the officers of the *Montgomery*, and inspected the company's works, including the pier, the three-fourths mile of canal, and the 11½ miles of railroad, and May 21 left in the river boat for the inspection of the San Juan, lightering over the Machuca, Castillo, and Toro Rapids, and stopping over at Castillo and Fort San Carlos, on the lake shore, where the San Juan was gauged and other observations made. Thence by lake to Granada, the survey party stopping off at Rivas, to prepare for the inspection of the western division.

Returning from Managua, the Board left Rivas May 29 for Brito, on horse and mule back, provisions and camp equipage going by ox carts. May 30 made examination of Brito Harbor, and returning went over the canal route thoroughly, in part on foot, to the mouth of the Rio Lajas on the lake.

June 5 inspected the harbor between Ometepe Island and the shore by means of the Government steamer *El 93*, and June 6 left Rivas for the return trip across the lake and down the river to Ochoa.

At Ochoa, June 9, the Board was met by Prof. Henri Pittier, of Costa Rica, who had been deputed by the President of that State to furnish all facilities possible for travel and information as to matters within the Costa Rica jurisdiction.

The Board is specially indebted to Professor Pittier for valuable information recently received with reference to volcanic and seismic phenomena in Costa Rica and Nicaragua, which might by possibility affect the permanence and stability of canal work, and his communication forms one of the appendixes to this report.

June 9 the Board and party left on foot for the journey through the forest, over the line of the San Carlos Ridge, and both the canal and embankment lines of the entire eastern division, gauging the streams and noting everything of interest in connection with the canal route, and arrived back at Greytown on the evening of June 18.

June 19 took the river boat and inspected the Lower San Juan and the Colorado River and mouth, and after further surveys of the Greytown Lagoon and an inspection of the company's buildings, sailed in the *Montgomery*, June 24, for Port Limon, Costa Rica.

Messrs. Davis and Stanford, of the Board's party, were left in Nicaragua, with instructions to make an examination of the vicinity of the Serapiqui River, to ascertain, if possible, the probabilities of finding sites for low dams. Mr. Davis's report is one of the accompanying appendixes.

From Port Limon the Board inspected the Costa Rica Railroad, en route to San Jose, where the courtesies and hospitalities extended by the President and the gentlemen of his cabinet command most grateful remembrance.

To the Hon. Lewis Baker, United States minister, and to M. C. Keith, esq., who built the Costa Rica Railway, the Board is indebted for valuable aid and information.

Before returning to the United States, the Board deemed it needful, as a means of ascertaining the stability of canal work in Central America, to make an examination of the present condition of the Panama Canal, and procured valuable evidence, corroborating observations in Nicaragua and Costa Rica, of unexpected permanence of embankments and excavations under a tropical rainfall.

At Colon the Board was greatly indebted to United States Consul J. L. Pearcy, and to Col. A. L. Rives, manager of the Panama Railroad, for unremitting hospitality, attention, and cooperation. The gentlemen representing the engineer staff of the canal company kindly gave the Board the use of steam launches both at Colon and Panama, for the examination of the sea level sections of the canal.

Returning to New York in the *Montgomery* July 21, the Board has since been engaged in the arduous task of a full and careful investigation of the canal company's records and data, representing a formidable accumulation—the work of many years.

The Board desires to take occasion to express its sincere obligation to the officers of the canal company for their ready and unfailing disposition to aid in every way in the investigation. The records have been placed freely and fully at the Board's disposal, and every facility given for their examination.

In its inspection of the canal route, the Board had the advantage of being accompanied by the chief engineer and an assistant, and it was found that the company had not only opened up the entire canal line ready for inspection, but had provided camps in the eastern division, provisioned them, and engaged a number of native porters. Every need of the Board for full inspection had been, as far as possible, anticipated, largely through the exertions of the official representative of the company at Managua.

It should be said at once that had it not been for the trouble taken and the large expense assumed by the company in making the arrangements indicated, the Board would have found itself, with the means furnished by the appropriation, crippled at the outset, as the clearing of the route and the construction and provisioning of camps would have drawn heavily upon both its time and its resources, and left little of either for the later investigations in New York and the preparation of the report.

The Board is aware, better perhaps than anyone else can be, of the inadequacy of its discussion of the features of the canal project.

The subject is one of great magnitude, and, before sound opinions could be formed, the entire matter had to be thoroughly studied and the great mass of data, some of it confused and some of it discrepant, formulated, recorded, and as far as possible digested.

The Board received its commissions at the hands of the honorable the Secretary of State April 25, and the act required the report to be made to the President on or before November 1. The interval since the return to the United States, July 21, has been devoted to unremitting labor, and no endeavor has been spared to make the information furnished in the report as complete as the circumstances permitted. That it is imperfect the Board regrets, and in justification can but plead the magnitude of the undertaking, the limited time and means available, and the lack of necessary data.

The act of Congress and the instructions from the State Department, of which copies are appended, are precise as to the scope of the investigation to be made by the Board. It was the "feasibility, permanence, and cost of the construction and completion of the canal" that was its clearly defined object, and it was the actual canal route itself, with possible deviations, and the "plans, profiles, sections, prisms, and specifications for its various parts" that the Board was to investigate.

This phraseology left no doubt as to the nature of the Board's duties. They were purely professional, and limited to the consideration of engineering data, and the Board has endeavored to the best of its ability, and in the light of the responsibilities imposed, to discharge the duties intrusted to it.

William Ludlow,
Lieutenant-Colonel, Corps of Engineers, United States Army.
Mordecai T. Endicott,
Civil Engineer, United States Navy.
Alfred Noble,
Civil Engineer.

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LETTER OF INSTRUCTIONS BY THE SECRETARY OF STATE.

DEPARTMENT OF STATE,
Washington, April 25, 1895.

GENTLEMEN: Pursuant to the provisions of that part of the sundry civil appropriation act (Public, No. 122) approved March 2, 1895, constituting a board of three engineers, to be appointed by the President, to make the survey and examination necessary in order to ascertain the feasibility, permanence, and cost of the construction and completion of the Nicaragua Ship Canal by a certain route mentioned in the act, and to consider the plans, specifications, and estimates therefor under such arrangements and regulations as shall be made by the Secretary of State with the approval of the President, you have been appointed by the President, who has selected you on account of your well-known fitness for the important work; and it is incumbent upon me, as Secretary of State, to communicate to you the following instructions, which have been approved by the President, for the guidance of the Board:

1. The Board will proceed to New York and there examine the engineering and other cognate data relative to the proposed ship canal which may be found of record in the office of the Interoceanic Canal Company or elsewhere.

2. Upon completion of this work, the Board will proceed to San Juan del Norte (Greytown), Nicaragua, by such means as are or may be made available, and personally inspect the route of the proposed canal and the termini thereof, and make such further examinations and verifications of data as shall be deemed necessary.

3. Upon the completion of its work in the field, the Board will return to the United States and engage in the preparation of its report in accordance with the requirements of the act.

4. For the prosecution of its work, and to facilitate to the utmost the procurement and formulation of the necessary data within the prescribed limits of time and within the appropriation provided by the act, the Board is authorized to purchase in open market such materials, including instruments, field outfit, provisions, and other supplies, as in its judgment are desirable and necessary for the purposes of the prescribed survey and examination, and to employ such skilled and other assistance as it may deem essential, and to pay such rates of compensation therefor as may be deemed proper.

5. The President has fixed the compensation of the members of the Board at $5,000 each in full of all services rendered under their appointment, as provided in the act.

6. An itemized account of all disbursements, with proper vouchers, will be submitted through the Department of State for audit; and Brt. Lieut. Col. William Ludlow, major, Corps of Engineers, United States Army, is hereby designated to act as the disbursing officer of the Board and to make requisition for funds and to account for the same.

7. A copy of so much of the act as relates to this subject is annexed for the guidance of the Board, attention being specially called to the requirement that it shall make report to the President on or before November 1, 1895.

I am, gentlemen, your obedient servant,

W. Q. GRESHAM.

Bvt. Lieut. Col. WILLIAM LUDLOW, U. S. A.,
Civil Engineer M. T. ENDICOTT, U. S. N., and
ALFRED NOBLE, Esq.,
Board to Survey and Examine the Nicaragua Canal Route,
Washington, D. C.

[Extract from act approved March 2, 1895.]

For the purpose of ascertaining the feasibility, permanence, and cost of the construction and completion of Nicaragua Canal by the route contemplated and provided for by an act which passed the Senate January twenty-eighth, eighteen hundred and ninety-five, entitled "An act to amend the act entitled 'An act to incorporate the Maritime Canal Company of Nicaragua,' approved February twentieth, eighteen hundred and eighty-nine," twenty thousand dollars, to be expended under the direction of the Secretary of State.

And a Board of three engineers is hereby constituted to make the survey and examination necessary for such ascertainment; said Board to be selected and appointed by the President of the United States; one from the Corps of Engineers of the United States Army, one from the Engineers of the Navy, and one from civil life; and the compensation of the members of said Board shall be fixed by the President, not to exceed five thousand dollars each, including such pay as the engineers so selected are receiving, for the time they are employed, from the Government. And the said Board, under such arrangements and regulations as shall be made by the Secretary of State, with the approval of the President of the United States, shall visit and personally inspect the route of the said canal, examine and consider the plans, profiles, sections, prisms, and specifications for its various parts, and report thereon to the President; and should they ascertain that any deviation from the general line of the proposed route is desirable they shall so state in their findings and conclusions with regard thereto in their report.

And said Board shall make their report on or before November first, eighteen hundred and ninety-five, and the appropriation shall be immediately available.

REPORT OF THE NICARAGUA CANAL BOARD.

GENERAL PHYSICAL DESCRIPTION

CHARACTERISTICS OF THE NICARAGUA BASIN.

The cordillera or mountain ridge that divides the Pacific drainage from that of the Atlantic, having crossed the northwest boundary of the State of Nicaragua and reached a point about 35 miles north of Lake Managua, separates into two branches.

The eastern divide, continuing the general southeast course, parallel with the northeast shore of Lake Nicaragua, and 20 miles distant from it, bears directly toward Greytown, on the Caribbean coast, sending a spur across the San Juan Valley at Ochoa, and terminates on the borders of the San Juan delta.

The western divide, first inclining southwest for about 50 miles toward the Pacific, heads Lake Managua, and thence goes southeast parallel with the Pacific coast, at an average distance of 10 miles, to connect with the main divide in the high ranges of Costa Rica.

The rectangular basin, inclosed on three sides by the two divides, has a length northwest and southeast of, roughly, 200 miles, with an average width of about 60 miles, and an approximate area of 12,000 square miles, covering Lakes Managua and Nicaragua and the territory draining into them.

There are no maps of Nicaragua based on accurate surveys, and scarcely any two agree. The distances, areas, etc., noted may, therefore, be considerably in error.

Lake Managua has a length of about 35 miles and a maximum width of 20, and discharges into Lake Nicaragua across the neck of land 14 miles wide that separates them, through the Tipitapa River, which has a length of 23 miles and a fall of about 25 feet from one lake to the other.

During the dry season the visible outflow from Lake Managua disappears and the bed of the Tipitapa is dry, and such surplus of supply over evaporation as may exist must escape through fissures in the rocky bed.

Lake Nicaragua has a length of 110 miles and a maximum width of 45, and an area of about 2,700 square miles.

The only outlet for the drainage of the basin is the San Juan River, which leaves Lake Nicaragua near its southeast end, and flowing parallel with the east divide range, at an average distance of 12 or 14 miles, sweeps round its southeast termination and discharges through the several channels of the delta which it has built out into the Caribbean Sea.

The San Juan is a fine stream of large volume even at low water, an average width of 300 yards and total length of 120 miles, flowing between stable banks clad with dense tropical vegetation, and is navigable for river steamers throughout its length, with the exception of some rapids in the upper portion that at low stages interrupt the passage of boats.

The valley of the San Juan on the north is limited by the east divide until the head of the delta is reached. It is therefore narrow and hilly and the affluents small. On the south side the conditions are reversed. The drainage area is bounded by the lofty crest line of the Costa Rican range 40 or 50 miles distant, the streams are large and torrential and in times past have brought down great quantities of sand and volcanic detritus.

In the upper reaches between the rapids the current is moderate, the bottom firm, and the water clear, but these characteristics change from where the San Carlos comes in, below which the bed of the San Juan River is of sand and the current turbid and strong.

The main volume of the river reaches the sea through the Colorado, leaving little more than 10 per cent to reach Greytown by way of the Lower San Juan.

Lake Nicaragua is notable for its generous dimensions, for the moderate elevation of its surface above sea level, and for the proximity of its west shore to that of the Pacific. The strip of land separating them is at the narrowest but 12 miles across, and at one point on the divide the elevation, 154 feet above sea level, is less than at any other that has been discovered on the isthmus.

These facts, in conjunction with the navigability of the San Juan River, which furnishes access to the lake from the Caribbean and permits vessels to reach a point so near to the Pacific, have from the earliest times attracted attention and given prominence to the Nicaragua route as a feasible means of communication across the isthmus.

The surface elevation of the lake, considering its large area and the capacity of the San Juan River to discharge the surplus waters of the drainage basin, varies within rather wide limits. The mean low stage has been taken at about 102 feet above mean sea level. It has been observed at 110 feet as a high stage, indicating a range of 8 feet, but from reliable data gathered by the Board its surface has been as low as 96½ and as high as 111, an extreme range of 14½ feet. These variations no doubt correspond to variations of rainfall which, in the Tropics as elsewhere, has its recurring periods of maxima and minima through terms of years, but of which there is no sufficient record, any more than of the oscillation of the lake, to enable the cyclic laws of sequence to be ascertained. These data are of importance in connection with the use of the lake as the summit level of a canal system, as affecting the design and construction of the depending works, and the consideration of future probabilities.

The lake has not been surveyed either for coast line or hydrography, but enough is known to warrant the conclusion that its general depth is ample for all purposes of navigation. A sounding of 109 feet is shown off Ometepe, which would put at least a portion of its bed near the sea level. At the southeast end, behind the Solentiname group, the shores are low and the lake becomes shallow, with a soft bottom. At 14 miles from shore the soundings show 22 feet at mean low lake, diminishing to 6 feet a mile from Fort San Carlos, where the San Juan has its outlet.

The coasts on both sides are, in general, rocky, the east side being the bolder, rising toward the 1,000 and 2,000 feet elevations of the east divide. Toward the northwest end of the lake the mountain of Mombacho occupies the shore and overlooks the city of Granada.

The prevalent wind is the east northeast trade, blowing across the isthmus from the Caribbean Sea and causing a moderate surf on the west shore. It varies in strength from calm to fresh, with occasional squalls and shifts of wind. Little is known of the force and direction of storms. If such occur, they must be of brief duration and no great violence, as there is no evidence at any point of severe wave action. The crib piers, loosely built of notched logs and half filled with stone, that do duty as wharves at San Jorge and Granada, would not stand an hour's blow on Lake Michigan, and the calm and shallow expanse at the lower end of the lake negatives any suggestion of a heavy sea from the northwest.

Numerous islands are distributed about the lake, some of them of considerable dimensions. The most conspicuous lies within a few miles of the west shore, about midway of the lake, with a length of 20 miles. From either end the superb cones of Ometepe and Madera rise to an altitude of a mile above sea level, dominating the landscape in every direction and incidentally furnishing excellent harborage between island and shore.

The pure and symmetrical concave outlines of Ometepe, its lower third buried in verdure, its steep upper slopes of sand and ash, pale-green and brown, according to the light, its pointed summit and plume of cloud trailing toward the Pacific, with heavier belts of vapor encircling it below, forming and dispersing with frequent changes, and gradually settling toward the base at nightfall, make a picture of surpassing beauty and interest. From the shore or lake its altitude can not be realized, and only from the interior, looking over an intervening elevation, is a true idea gained of the scale on which it is constructed.

Fourteen miles northwest of Ometepe is another mountain island, Zapatera, where numerous ancient and gigantic stone images are found concealed in the heavy forest.

The geologic history of the Nicaraguan basin is obscure. Glacial action, submergence, emergence, volcanic eruptions, and seismic convulsions have all played their part in the tumultuous and chaotic past, to confuse the record and puzzle the observer of to-day. There is good reason to believe that, so far as the more violent phenomena are concerned, which were centralized along the line bordering the Pacific, now marked by the range of peaks at frequent intervals, the forces that produced them are practically exhausted. The latest volcanic outburst of any moment was one hundred and twenty-five years ago, when the volcano of Masaya, 15 miles northwest of Granada, poured a stream of lava 10 miles toward Managua. Momotombo, rising 6,000 feet above sea, on the north shore of Lake Managua, 90 miles distant from the canal route, and some of the still loftier Costa Rican volcanoes, 60 miles or so southeast from Lake Nicaragua, still give evidence of a moribund vitality, but the intervening peaks seem almost if not quite at the point of extinction.

As far as earthquakes are concerned, it is true that tremors occur from time to time, as in other countries, our own for example; but for a very long period there has been no such destructive action in Nicaragua as accompanied the Charleston earthquake.

There seems no reason, therefore, to apprehend a disturbance serious enough to imperil the stability of canal constructions, at least any of such moment and imminence as would warrant the abandonment of the enterprise, if in other respects its execution were deemed advisable.

There is a marked difference in characteristics between the regions lying on either side of the lake. The Atlantic slopes are generally a confused mass of steep clay hills, heavily timbered and interspersed with deep swamps and level bottoms. Cultivation and population there are none, with the exception of the occasional clearings along the banks of the San Juan.

On the west side the soil is volcanic tufa or decomposed lava, most of it extraordinarily fertile. The country is more open, the forest growth less heavy, and the variety of products, natural and cultivated, remarkable. On this side are concentrated the bulk of the population and the wealth of agricultural products.

HARBORS.

The west coast of Nicaragua has excellent harbors, the best of which, however, viz, the Gulf of Fonseca and the bay of Salinas, lie at the territorial limits of the State.

The principal one is Corinto, in the northern province of Chinandega, whence there is communication by rail and steamboat with Managua and Granada.

San Juan del Sur, 8 miles southeast of Brito, is small and with steep slopes inland.

Brito is merely an indentation in the coast line at the mouth of the Rio Grande.

On the Caribbean coast the principal harbor is Bluefields, about 70 miles north of Greytown, where there is an ample inclosed bay, and the Bluefield River is navigable for a long distance inland. A railroad is projected from the head of navigation to reach San Ubaldo, on the east shore of Lake Nicaragua. The condition of what once was the harbor of Greytown is elsewhere stated in this report. The mouth of the Colorado has a depth of 8 to 12 feet on the bar and ample harborage inside, but the entrance is a shifting and dangerous one, complicated by the powerful current of the river and the detritus carried down by it.

The range of tide in the Caribbean is about 15 inches, and at Brito, on the Pacific, about 9 feet.

As nearly as has been determined, the mean sea level is the same in both.

RAINFALL AND DRAINAGE.

The most serious problems affecting the design and construction of a canal system at the present time are those involved in the heavy rainfall and consequent discharge from the lake and streams, whose variations of surface and volume must be taken into account.

On these points the existing data are seriously defective, both in respect of number and continuity.

There is a rainfall record at Greytown for the three years 1890, 1891, and 1892 which shows a mean of 267 inches, a maximum of 297, and a minimum of 214.

A record at Rivas, on the west side, kept by Dr. Flint, an American resident, for the years 1880 to 1894, gives a mean of 65 inches, a maximum of 105, and a minimum of 32.

In addition to these, there is reliable information of precipitations of 3 inches in an hour, of 9 inches in nine hours, and 35½ inches in eight days.

A record of nearly 25 feet of water in a year on the Caribbean coast, diminished to 5½ feet between the lake and the Pacific, needs no comment to indicate the important results that must ensue with reference to matters of local drainage and engineering constructions.

It would be of value if intermediate points had been occupied, and the diminution of rainfall traced from Greytown to Brito, but the observations in this respect are scattering and unsatisfactory.

Similar variations in precipitation are found between Colon and Panama, and it is evident that the water-laden trade winds deposit the greater portion of their burden before passing the divides, although there is reason to believe that when an opening occurs, as, for example, the broad lower valley of the San Juan, the heavier downpour may locally continue for a considerable distance upstream beyond the dividing range.

But it is with reference to the effect of this precipitation in the varying volume and floods of the lake and rivers that the deficiency of data is most keenly felt, since it is upon information of this kind, accurately recorded and carefully studied, that depends the solution of the serious engineering problems involved in the matter of canal construction.

The height, cross section, and volume of cuts, dams, and embankments, and the dimensions of locks, weirs, and sluices to be constructed for the maintenance and utilization of the summit level, the precautions to be taken to make these works secure, and the loss in elevation of water surface due to droughts or deficiency, all these depend for their determination upon the fullest and most precise gaugings of all the water courses concerned, following their variations of volume and velocity throughout their range; and, even with these most carefully ascertained, allowance would still have to be made for possibilities occurring at long intervals.

This information has not been secured. The survey by Colonel Childs in 1851, and that by Commander Lull in 1873, made some gaugings during the brief period of the field work, but took account mainly of low-water data only, to determine if there was a sufficient supply for an ordinary low-level canal.

The canal company has omitted attention to these matters, and made no careful gaugings at any point, and this omission is the more to be regretted, because the company's project calls for the construction of numerous dams and embankments of magnitude, some of them without precedent in engineering practice, and all involving serious hydraulic problems.

While the variations of precipitation are great, the average annual cycle in Nicaragua is fairly simple.

The rainfall follows the sun; greatest when passing the zenith, less when farthest north, least when farthest south. This gives a "wet season," beginning in late May or early June, culminating in July and August, diminishing in September, increasing again in October and November, and falling off in December. From January to April, inclusive, is the "dry season," a nominal one at Greytown, where rain may fall on any day in the year, but much more marked on the west side, where for several months the rainfall will be small or intermitted altogether. In the former case the air is always humid; in the latter it may be dry and parching for considerable periods, with corresponding effects upon vegetation and soil.

CLIMATE.

The climate of Nicaragua is commonly misunderstood, and it is not realized that every summer in the United States gives a thermometric record higher than at any time in Nicaragua, where it seldom exceeds 90° or falls below 70°, making an average range of about 20°.

These temperatures, which represent what would be a moderate summer heat in the United States, in Nicaragua continue throughout the year, and it is this fact, in conjunction with the high humidity, that so seriously reduces the value of physical labor in the Tropics.

The trade winds blow from the sea with a mild persistence that is very grateful in the shade, but prolonged exertion is exhausting, and the net product is much less than in temperate zones. It is important that account of this fact be taken in estimating for the cost of the work.

The question of healthfulness must also be referred to in this connection. There seems little reason to believe that the general conditions in Nicaragua involve any special rate of mortality. So far as statistics are attainable, they indicate healthful conditions and the absence of epidemics. There has never been any yellow fever at Greytown, for example, except when imported, and those cases were readily isolated and cured. The prevalent diseases are mild types of remittent and intermittent fevers, occasionally of a pernicious and fatal type. There is no typhoid. Consumption is rather frequent, and skin diseases common among the natives.

The causes of this comparative exemption from the curses of other tropical climates are probably two: The trade wind blowing with much steadiness landward constantly renews the atmosphere with the sweet sea air, and carries off or dilutes unsanitary emanations. The heavy rainfall washes the air and furnishes an abundance of fresh drinking water condensed from the ocean vapors.

With pure water and pure air and a moderate equable temperature, the hygienic conditions are certainly favorable, and only human ignorance and neglect of sanitary precautions would occasion an excessive mortality. These are the normal and natural conditions, which, however, may be greatly modified when excavations are made, the rich humus, charged with decomposing vegetation, exposed, and the malarial fungoids taken up by the atmosphere. It is in these conditions that have occurred the heavy death rates on the Panama Railway and Canal, and, as ascertained by the Board, on the line of the Costa Rica Railway from Port Limon to San José. The natives suffer from these artificially produced endemics or epidemics as well as foreigners, and, as might be expected, it is the Jamaica negro who comes nearest to securing exemption. When the railway was building, great drafts were making on the Jamaica population for the Panama Canal, and labor was sought elsewhere. The United States negroes were neither procurable in sufficient numbers nor adapted to the climate. The Chinese imported are stated to have died like sheep, and of a large number of Italians brought in but a small proportion ever returned.

In case of building the Nicaragua Canal, it will be needful probably to call upon the population of Jamaica for the necessary labor. This is represented to be about 400,000, and 15,000 or 20,000 could be brought over under contract.

They make good laborers when well handled and controlled, as compared with other inhabitants of the Tropics, and adapt themselves more rapidly to new conditions.

The Nicaraguan natives are less effective for work to which they are unaccustomed. They make excellent porters, woodsmen, and river boatmen, but for labor with pick and shovel or a barrow would be found undesirable and probably not procurable at all.

For the working camps, the sanitary requisites would be an ample supply of fresh rain water delivered on the ground, and good food, with plenty of plantains and fruit; shelter and dry floors, dry bedding, ample bathing facilities, and no grogshops.

The climate and other conditions call for moderation in food and drink and an almost entire abstinence from the use of alcohol, which should be reserved strictly for medicinal purposes.

With the additional precautions of wearing light woolen clothing next the skin and the prevention of anything like constipation, the natural hygienic conditions in Nicaragua are as good as elsewhere, and perhaps superior to those prevailing, for example, in certain malarial districts in the United States.

GENERAL DESCRIPTION OF THE NICARAGUA CANAL PROJECT.

The canal project now under consideration is a gradual development due to successive investigations made at intervals during the past fifty years, and, for a better understanding of the matter, the history of these may be briefly reviewed.

THE CHILDS PROJECT—1852.

The first authentic survey and actual location of a canal route across Nicaragua were made by Col. O. M. Childs in 1850, 1851, and 1852, at the instance of the then existing Transit Company, which had established transisthmian communication with California by steamer from Greytown via the San Juan River to Virgin Bay on the west shore of Lake Nicaragua, and thence by stage to San Juan del Sur, a small natural harbor on the Pacific coast, about 8 miles southeast of Brito.

The river navigation proved troublesome and uncertain at low stages, and the Transit Company sought means to better these conditions, and to continue the water route across the narrow neck of land that separates the lake and the Pacific, with the object of securing a continuous depth of 17 feet.

Colonel Childs, an expert canal and railway engineer, of high repute in his day, was engaged to make the surveys, and his report, which has constituted the basis of all subsequent investigations and is still a valuable source of original information not elsewhere found, evinces the thoroughness with which his work was done.

He examined the several possible routes between the lake and the Pacific, and decided in favor of a line via the Rio Grande and Lajas Rivers—the former an ocean and the latter a lake affluent, between the head waters of which the divide was lower and the route more practicable than at any other point. The line determined Brito, at the mouth of the Rio Grande, as the Pacific terminus, notwithstanding its lack of natural advantages as a harbor.

Childs found the ordinary high level of the lake to be about 108 feet above mean sea level, and proposed to hold it at that elevation by means of two dams, one at Buen Retiro, in the Rio Grande Valley, 9¾ miles west of the lake, and the other at Castillo, in the valley of the San Juan, 37¼ miles east of the lake. The distance across the lake from the mouth of the Lajas to Fort San Carlos, where the San Juan River leaves it, being 56½ miles, the total length of summit level, was 103½ miles.

To continue the canalization of the San Juan below Castillo were six more dams, the lowest at a point one-half mile below the mouth of the Serapiqui, and 91 miles from the lake, where the canal was to leave the river and follow its left bank to Greytown, at that time an excellent harbor.

The difference of elevation between summit and sea level was to be overcome by 14 locks on each side, with a maximum lift of 8 feet.

The total length of the proposed navigation was 194.4 miles, made up as follows:

	Miles.
Canal between Brito and the lake shore	18.6
Across lake, Lajas to San Juan River	56.5
Slack water in San Juan by seven dams	90.8
Canal to 17 feet water in Greytown	28.5
Total	194.4

The locks were to be 250 by 60 by 17 feet, the bottom width of the canal 50 feet, increased to 90 feet at turn-outs, and of excavated channels in river and lake 150 feet.

The total estimated cost of the project, including 15 per cent for contingencies, was $31,538,319, based on the supposition that on the average the expense for construction would be about double the cost of similar work in the State of New York. In a supplementary report, Colonel Childs provided for raising the summit level 3 feet higher, viz, from 108 to 111, by making a corresponding increase in the height of the terminal dams at Buen Retiro and Castillo, with the object of reducing the cost of deepening the navigation in the upper 37 miles of river and out to deep water in the lake.

THE LULL PROJECT—1873.

In 1872 a United States Government expedition was fitted out for the reexamination of the Childs route. The final report of the exploration, including location and estimates for a canal, were made under date of December 1, 1873, by Commander Lull, U. S. N., with whom was associated as chief civil engineer Mr. A. G. Menocal, the present chief engineer of the canal company.

The Lull project contemplated a canal of 26 feet depth. It lowered Childs's summit level to 107 feet, and on the west side, instead of the Lajas, adopted the valley of the Medio, a lake affluent 3½ miles to the northward, as a means of reaching the valley of the Rio Grande, which was thence followed to Brito. The Medio had a much higher divide than the Lajas, involving more excavation, but was a trifle shorter, and believed preferable as a means of avoiding interference with the canal by the discharge from the upper valley of the Rio Grande. For the ascent to the lake, 11 locks were projected, with maximum lift of 10½ feet. For the canalization of the San Juan 4 dams were to be built, the uppermost at Castillo, the lowest at a point 66¼ miles from the lake and 1 mile below the mouth of the San Carlos River. To avoid complications from the discharge of this important stream, it was proposed to cut a new channel for it to the San Juan River below the dam. The canal was to leave the river at this point and follow the left bank to the outlet of the San Juanillo, and thence to Greytown by an almost direct course.

Ten locks of maximum lift of 10.87 feet furnished the means of descent from the lake to the Caribbean.

The total length of the Lull summit level was 102 miles, and of the navigation from Brito to Greytown 181¼ miles, made up as follows:

	Miles.
Canal from Brito to lake at mouth of Medio	16¼
Across the lake, Medio to San Juan River	56¼
Slack water in the San Juan by four dams and short canals	66¼
Canal to Greytown	42
Total	181¼

The locks were to be 400 by 70 by 26 feet, the bottom width of canal 50, 60, and 72 feet in different sections, of excavated river channel 80 feet and lake channel to — feet.

As Greytown Harbor had been destroyed since Colonel Childs examined it, the cost of its restoration, including an item of $100,000 for shutting off the Lower San Juan River from the harbor, was estimated at about $2,500,000, and the estimated cost of the entire project, including 25 per cent for contingencies, was $65,722,147.

The instrumental work by the Lull survey was not adapted to much more than a preliminary location, the levels were not checked, and for the 66½ miles of river to the lowest dam below the San Carlos the transit and level line covered about 26 miles only, the remainder being run with a gradienter, used by the hydrographic party under Lieutenant Miller, U. S. N.

The unit prices used in computing cost, as is to be inferred from a statement in the report by Mr. Menocal to Commander Lull, were apparently based on the supposition that they would not exceed those for similar work in the United States.

MR. MENOCAL'S PROJECT—1885.

In 1885 Mr. Menocal, under Government direction, made a partial reexamination and relocation, and the results are given in his report of November of that year.

The project was for a depth of 28 feet and in some places 30 feet. On the west side the route adopted was substantially the original one of Childs via the Lajas and Rio Grande, provision being made for the diversion of the upper course of the latter stream. The summit level in the lake was to be raised to an elevation of 110 feet above mean sea level, and this height overcome by four locks with a maximum lift of 33 feet.

For the canalization of the San Juan a bold measure was proposed, viz, the construction at Ochoa, a point 3½ miles below the San Carlos River and 69 miles distant from the lake, of a dam in the San Juan River which would have a height of nearly 60 feet above water surface, and by flooding the valleys of the San Juan and San Carlos convert them into an extension of the lake itself, whence the canal could abandon the river altogether and go eastward at the higher elevation directly toward Greytown.

To provide both for the maintenance of the lake level at 110 feet and for the discharge of the San Juan, a slope of 4 feet was assumed for the entire distance, and it would therefore be at the elevation 106 feet, or about 60 feet above the river at low stage, that the canal would leave it and carry the water level eastward. In order to do this it would be necessary to build extensive dams across the valleys of several small streams, the San Francisco being the largest, which discharge into the San Juan, and convert them into basins connected by short lengths of canal, and beyond these constructions to cut through the eastern divide, with a maximum depth of about 320 feet, in order to reach the valley of the Deseado, flowing toward Greytown. The distance through the basins from the San Juan to the west side of the divide cut is 12 miles, and through the divide cut 3 miles, whence descent is made in the Deseado Valley to sea level by means of three locks, one of which has a lift of 53 feet, and by a canal 16½ miles in length to Greytown.

By this bold expansion of the earlier projects a material shortening of the line would be effected, as well as a valuable extension of the unobstructed navigation of the summit level.

The total distance from Brito to Greytown is stated at 169.8 miles, made up as follows:

	Miles
Brito to lake	17.27
Lake Lajas to San Juan	56.50
Slack water in the San Juan	64.54
San Franscisco Basin Ochoa to eastern divide	12.01
Cut through the eastern divide	3.00
Canal to Greytown	16.48

The total length of summit level is given at 144.8 miles.

A discrepancy in river distance between the lake and Ochoa, more particularly referred to hereafter in the detailed account of the river navigation, occurs first in the report of 1885, and calls for an addition to the length of summit level, and to the entire navigation of about 4 miles. Lull used about this length of short canal in the river, and deducted it from the river navigation proper. This reduced river length has by inadvertence been carried forward into the 1885 and subsequent reports as the total length of the river navigation.

Making the correction, the summit level would be about 149 miles and total navigation from sea to sea 174 miles.

As designed in 1885, the locks were to be 650 by 65 by 29 feet; the bottom width of canal 80 feet, increased at the terminals to 120 feet; of excavated channel in river 125 feet, and in lake 150 feet.

The estimated cost of the project, including 25 per cent for contingencies, was $64,036,197; but the item for contingencies is made to include the cost of surveys, hospitals, shops, management, and other necessary expenses, in addition to the construction contingencies proper.

It is admitted in the text of the report that the cost of work in Nicaragua should be estimated as greater than in the United States, but the unit prices adopted do not indicate that the necessary allowance has been made in all cases.

No borings were made to ascertain the depth of foundation, presence of rock, distribution of materials, etc.

The Ochoa Dam was to be built of concrete, with foundations 20 feet below the river surface, the depth of water varying from 6 to 17 feet, but the nature of the subjacent river bed was not ascertained, nor was it then known that to retain the water level in the San Carlos Valley at 106 feet, an extensive system of embankments would be required along its eastern coast.

THE CANAL COMPANY'S PROJECT—1890.

Under the direction of the company, eight survey parties were employed, from December, 1887, to June, 1888, when the number was reduced to two or three. A still larger force worked from the spring of 1889 to the summer of 1890, when the parties were gradually dispensed with, and the last one withdrawn in 1891. Borings were continued to as late as 1893.

The eight parties comprised six land parties, one hydrographic party, and one boring party.

Borings were made along the line of the canal; the western division, lake to Brito, was relocated, and Greytown Harbor surveyed. Brito Harbor and the east and west sides of the lake were examined and the San Carlos Valley and east crest line explored. A low-level line in the San Juan Valley was located eastward from the Ochoa Dam, but most of the survey work was directed to developing the difficult topography over the high-level line through the San Francisco Valley and the east divide cut along the line originally proposed by Mr. Menocal in 1885.

The resulting project as set forth in the final report on location by the chief engineer under date of January, 1890, and further elaborated in a paper prepared by Mr. Menocal for the Chicago Water Congress in 1893, is substantially that of 1885, with some modifications and an important addition.

The striking and novel features of 1885 are retained. The high-level dam at Ochoa, the long series of embankments through the San Francisco basins, the 3-mile cut through the east divide and the locks of high lift are adhered to.

Additional basins and dams are added in the Deseado Valley east of the divide cut, provision is made for embankments along the east crest of the San Carlos Valley to retain its flowage line at an elevation of 106 feet, and most important of all, the extension of the summit level westward from the lake is provided for by the construction of another high-level dam at La Flor, a contracted point in the Rio Grande Valley 3.8 miles from the Pacific, converting the valley above into a basin 4.6 miles long at the lake level, and making a corresponding reduction in the length of excavated canal.

The elevation of the summit level is retained at 110 feet and its length increased to 153¼ miles, the total distance from Brito to Greytown being 169½ miles. These two data require the addition of about 4 miles of river, as before noted.

Sea level is reached on each side by three locks, with a maximum lift of 45 feet and dimensions 650 by 70 feet. The bottom width of the canal is 80 and 120 feet, of the river channel 125 feet, and lake channel 150 feet. The depth in the terminal canals and in the river is 28 feet, and elsewhere 30 feet. Through the rock cuts of the east and west divides the channel is 80 feet wide and 30 feet deep, with vertical sides.

Some proposed construction details may be noted. The high level dams at Ochoa and La Flor, as well as the heavy embankments in the San Francisco and Deseado basins, are to be built of assorted rubble from the divide cuts, backed with clay, and these dams are in most cases to act as weirs for the discharge of surplus water over their crests and down the rear slopes.

The diamond-drill borings made at the site of the La Flor Dam were extremely unfavorable to its construction, and the earth auger borings made at the site of the Ochoa Dam indicated sand as deep as 25 feet below the bed. Judging from the depth of the river section below the San Carlos, the sand underlying the Ochoa site may be 50 or 60 feet in depth.

The slope of 4 feet in the river, from the lake to Ochoa, assumed in the 1885 project, is retained as a datum for the water surface elevation at Ochoa, and the heights of other dams and embankments, and depth of cuts.

The basis for the computation of water supply from the lake summit level, as given in the report, is the assumed minimum and maximum discharge of 11,390 and 18,059 cubic feet per second, respectively, from which an arithmetical mean of 14,724 cubic feet is deduced, as the mean discharge from the lake, with which the maximum amount needed for lockage is compared to show that the lake discharge is ten times greater than necessary for this purpose, and allows an ample margin for losses due to leakage through the dams.

Both the maximum and minimum discharges assumed are greatly in error, and, in any case, the available supply will be measured, not by a mean, however computed, but by its minimum, whatever that may be.

In the present case there is reason to believe that the maximum may be double, and the minimum as little as one-half or one-third that assumed. But, independently of the actual quantities, which are not known, the company's computation overlooks the important fact that the lake has a range, varying doubtless in series of years, of from 5 to 15 feet between the highest and lowest stages, rising during the wet season and falling during the dry season. The fall is due to two principal causes, viz, the discharge by river and the loss by evaporation, which, for so large an area, may be more than equivalent to the visible outflow at low stages.

The low-water discharge represents, therefore, not supply at all, but reservoir loss, which must be controlled if the summit level elevation of 110 feet is to be maintained, and the maintenance is essential if the depth of channel in lake and river is not to be materially reduced.

To prevent the lake from lowering it will therefore be necessary, not merely to check the discharge during the dry season, but to store water at a higher elevation than 110 feet toward the close of the wet season, in order to allow for losses by evaporation and necessary uses, which for several months will be in excess of the natural accessions from rainfall and inflow from the lake watershed.

This matter is elsewhere treated more in detail, and is referred to here for the reason that it constitutes one of the most serioms problems in connection with the canal construction, and illustrates the importance of a thorough investigation of all hydraulic data pertinent to its solution, as regulating the height and dimensions of every dam, weir, and channel section along the summit level.

For example, in the 1893 Chicago paper, which gives more elaborate data than the final report of 1890, the Ochoa Dam is to have a weir on its crest 1,250 feet long, and at an elevation of 105 feet, while the weirs in the San Carlos Ridge, with a length of 1,200 feet, are fixed at an elevation of 103.5 feet.

The computation is made that, with these arrangements and the river surface at 106 feet, the discharge over the weirs will be at Ochoa 2,900 cubic feet per second, and at the San Carlos weirs 11,300, a total of 14,200 cubic feet, which equals the computed mean discharge from the lake. During the dry season it is evident that if the low-water flow of the river becomes less than this the 106-foot elevation can not be held, and the river at Ochoa will run down to the lowest outlet it can find, which will be the sill of the San Carlos weir, at an elevation of 103½ feet, and the depth of navigation to the eastward will be reduced by 2½ feet. At the same time it may be observed that to regulate the discharge of high water from the lake and prevent its rising to an undue and damaging height is also a difficult matter, the consideration of which is involved with that of the control of the low-water period, both depending upon hydraulic data not now available.

Note may also be taken of the results to the river navigation below the Ochoa Dam, due to the suspension during the dry season of the lake discharge. It will have to depend upon the Serapiqui and a few other small affluents, and the main river bed will be practically dry.

The company's surveys, other than the borings, were mainly topographical and did not include the procuring of hydraulic data. Few gaugings of value were made for this purpose, and there was no survey of the San Juan at all, or endeavor to ascertain its regimen, or of that of the lake.

The total cost of the canal is stated in the company's estimate of 1890 at $65,084,176, including 25 per cent for contingencies, which, however, as in 1885, cover the cost of shops, hospitals, and management also. The unit prices used are in general somewhat less than those of 1885.

The company's estimates include an item of $275,000 as representing the cost of a canal to connect Lakes Nicaragua and Managua via the Tipitapa River.

The connection constitutes no portion of the ship-canal project, and has not been investigated by the Board. Its appearance in the company's schedule is due to a requirement in the concession from the Nicaragua Government.

There are no estimates of the damages that may be incurred by reason of the submergence of lands, and in the absence of any data the Board has not endeavored to ascertain what amount should represent this item.

Subsequent to the final report of 1890 several important changes have been made in the project as indicated in the Chicago paper above referred to, in the Board's correspondence and interviews with the chief engineer, and otherwise.

These may be briefly referred to.

The company's recent publications make the lock width 80 feet instead of 70 feet. This is an error, as, for the present at least, the 70-foot dimension is retained.

The position of lock 3, east of the east divide cut, and terminating the summit level, has been moved westward to a better location, and the dam is to be of concrete, with a sluice in it. The maximum lift of locks is reduced to 40 feet. The east divide cut is widened from 80 to 100 feet. The dams and embankments of the Deseado and San Francisco basins are to be of clay instead of rock fill, and are not to be used as weirs for surplus drainage; sluices and separate weirs being proposed for that purpose.

The height and volume of the embankments has been greatly augmented and extensive excavations added for foundations in mud bottoms.

The cube of the Ochoa Dam has been increased one-half, and concrete sluices have been provided for the San Carlos Ridge.

The rock cut through the west divide has, like that in the east divide, been widened from 80 to 100 feet.

A concrete core wall is added to the La Flor Dam and a separate waste weir provided, and the estimates for the western division locks largely increased.

As these modifications call for large additions to the quantities and cost scheduled in the detailed estimates of 1890, the company, at the request of the Board, revised the data, and the result is given in the accompanying table of estimates of date 1895.

The total cost of the project as now estimated by the company is $66,796,800, about $1,700,000 in excess of the total of 1890.

On comparing the two schedules, it is seen that, while important enlargements of and additions to the proposed works have been made, the increase in total cost is in much less proportion by reason of reductions in the assumed unit prices and in the item for contingencies.

If the quantities estimated in 1895 are computed with the same unit prices as in 1890, and the same allowance be made for contingencies, the cost of the revised project will be $78,427,534 instead of $66,796,800, an increase of $11,630,000.

The matter of unit prices has been carefully considered by the Board in the light of all the information that could be obtained, and the table of estimates indicates the result, the matter being more fully discussed elsewhere in this report.

It must be noted, however, that the company has made no final detail or construction drawings so far as is known, and general data are relied upon for computing cost; the only specifications drafted are those for the dredging work, and the particulars as to this are in some cases lacking in definiteness.

The Board does not believe that in the circumstances affecting the cost of work in Nicaragua, climate, rainfall, enforced importation of labor and material, absence of local mechanical and other facilities, etc., and with the experience gained in similar work at Panama and in Costa Rica, the unit prices adopted as the basis for computation could be safely reduced.

The several portions of the canal project will be discussed in detail under separate heads, beginning at Greytown and proceeding westward.

For convenience, three general designations will be used:

(1) The eastern division, from the Caribbean to the San Juan River at Ochoa.

(2) The lake and river division, from the Ochoa Dam to the west shore of the lake.

(3) The western division, from the lake to the Pacific.

The company's estimates include items for lighting the various sections of the canal, aggregating in all $373,000. The Board has made preliminary estimates for the same purpose, finding occasion to increase largely the estimate for Brito Harbor and at some other points, and diminish the requirements where the company provides for electric lighting elsewhere than at the locks.

The total figures provisionally estimated by the Board are $500,000, on the general principle that there should be a light about every quarter of a mile, and in curves twice this number.

The Board is of opinion that while the canal sections and basins can be so lighted as to permit of navigation at night, this will be found a very difficult matter in the case of the 69 miles of river between the Ochoa Dam and the lake. The navigation here will be sufficiently difficult in the daytime for long, heavy vessels traversing channels of considerable curvature in a current that during the rainy season may reach 2 or 3 miles an hour, particularly in view of the fact that the submerged channel is without banks.

The estimate, however, includes lights for the river.

For the lake channel, range lights are needed to mark the axis of the 14 miles of cut, with three pairs of skeleton beacon lights in the lake bordering the cut, an additional light at Fort San Carlos on the north bank, a light on the Bocas Islands half a mile northward of the canal entrance, another on the north end of one of the Solentiname Islands, and one on the south end of the Madera Island.

The canal entrance on the west shore should have lights on both pier ends and each side of the canal.

The main lights at the harbors should be first-order seacoast lights, of the best construction and efficiency known to the service.

REGULATION OF SUMMIT LEVEL.

In the project of the company the lake is to be maintained at a minimum elevation of 110 feet above mean tide by means of the Ochoa Dam and the embankments in the San Carlos Ridge and along the line between Ochoa and the east divide. After the construction of these works, it is expected that the river at extreme low stage will have a fall of 4 feet from the lake to the Ochoa Dam, a distance of 69 miles, giving a minimum elevation of water surface at the dam of 106 feet. The heights of the dams, embankments, and regulating weirs are determined with reference to this elevation. In the report of 1890 (pp. 21 and 22) the discharge from Lake Nicaragua at its lowest stage is said to be 11,390 cubic feet per second, and Colonel Childs is quoted as authority for an estimate of high-water discharge of 18,059 cubic feet per second. With these data a calculation is made, using the numerical mean of the two results to show that there will be a much larger water supply than required for canal purposes. Both the data and the method employed in this calculation are incorrect.

In Appendix C are given the results of all the gaugings of the San Juan River of which the Board has been able to find record. They consist of a series of gaugings made at different points along the river by Colonel Childs in 1851; of a similar series made by Commander Lull in 1873; of a single gauging made by the canal company in 1888, and of two gaugings made by the Board in 1895.

All the measurements of the discharge of Lake Nicaragua have been made at low stage, but none at the lowest. The gaugings of Lull and Childs at this point agree as nearly as can be expected of gaugings made hurriedly and at such a long interval of time. The stage of the lake at the time of Lull's gauging, 102.28 feet above mean tide, has been erroneously accepted by the company as extreme low water. At the time the gauging at Fort San Carlos was made by the Board, May 26, 1895, the stage was 101.8 feet, and the measured discharge 9,420 cubic feet per second, which accords very well with the results of Childs and Lull. A lower stage than this, however, has been of record more than twenty years. On the 2d of May, 1872, according to Lull's profile, the lake was 100.87 feet above mean tide. Still lower stages have been reported; the officers of the *Victoria*, a steamboat plying on Lake Nicaragua, showed to the engineers of the canal company a low-water mark whose elevation was 98.6 feet; this was confirmed by residents at the head of Tisma Lagoon, near the mouth of the Tipitapa River, at the head of Lake Nicaragua, who pointed out a ledge of rock extending across the river, which has been bare; its elevation is 98.5 feet. The very lowest stage known, observed at Granada, on the west side of the lake, is reported by Mr. William Climie, an English civil engineer, who has resided in Nicaragua for many years. Mr. Climie reports a stage of 96.6 feet above mean tide. This report, coming from a trained civil engineer, is entitled to great weight.

No measurement was made of the discharge of the lake at any of these low stages, but calculations indicate a discharge of 5,800 cubic feet per second at the stage reported by the officers of the *Victoria* (98.6 feet), and 3,400 cubic feet per second at the lowest stage reported (96.6 feet).

These data as to low-water discharge are not, however, sufficient for the solution of the problem of the maintenance of lake level. For this purpose the lake must be treated as a reservoir. If the inflow during the dry season is less than the amount lost by evaporation, plus the amount required for canal purposes, water must be stored on the approach of the dry season and the surface of the lake raised above the established minimum stage.

There is hardly any definite information as to the amount of water received by the lake during the dry season. Lull's gaugings, made at several points on the San Juan in 1873, when the river was at a low stage, showed that the tributary streams added little to its volume.

From the Atlantic coast, where in ordinary years there is no dry season, to the Pacific, where in ordinary years very little rain falls for five months, there is a more or less gradual reduction as regards rainfall, varied by the presence of heavily forested districts and ranges of hills and mountains. The mean annual rainfall at Greytown for three years (1890, 1891, and 1892) was 267 inches; at Rivas, between Lake Nicaragua and the Pacific, the mean for the same years was 59 inches.

No rainfall observations have been made between Rivas and the east divide, except for periods of a few days, and the rainfall on the eastern watershed of the lake is not known. There is, however, a dry season, although shorter than on the west side. It may be assumed, although with much uncertainty, that on the east side of the lake the dry season continues for four months. For a considerable time after the beginning of the dry season the streams continue to flow, their discharge becoming less and possibly ceasing altogether. For the present purpose it is assumed that during a period of two months the streams are dry, the lake receiving no water whatever. In order to make an estimate of the amount of water to be stored before the opening of the dry season account must be taken of evaporation and requirements for lockages and leakages.

The rate of evaporation in the dry season on the Isthmus of Tehuantepec was ascertained by Captain Shufeldt to be 0.19 inch per day. On the Isthmus of Darien it was found by Commander Selfridge to be 0.20 inch per day. The latter rate will be adopted here for Nicaragua.

For calculating the amount required for lockages it is assumed, as in the company's estimate, that the maximum traffic through the canal will be 32 vessels per day. If all were moving in one direction each would require two lockfuls, less the submerged volume of the vessel; if moving alternately in opposite directions each would require one lockful, less the submerged volume of the vessel. The mean may be taken neglecting the volume of the vessel, or one and one-half lockfuls for each; then, the maximum lift of the lock on the Atlantic side being 40 feet and on the Pacific side 42½ feet, and the lock chamber being 650 feet long and 80 feet wide, there will be required per day 102,960,000 cubic feet.

This amount, divided by the area of the summit level, in square feet, will give the daily lowering of the summit level in consequence of lockages.

The area of the lake is taken at 2,700 square miles; the area of the San Juan between the lake and the Ochoa Dam, plus the area of the smaller valleys and basins submerged, will be about 110 square miles, making the total area of the summit level 2,810 square miles, equal to 78,338,304,000 square feet.

The summit level will then be lowered each day by drawing off water for lockages 0.0157 inch.

The leakage at the locks and sluices may be as much more.

There will be a considerable leakage through the Ochoa Dam and through the 7¼ miles of embankment. The amount can only be conjectured, but for this estimate will be taken as 5,000 cubic feet per second, or 432,000,000 cubic feet per day. This will lower the summit level each day 0.0661 inch.

Collecting these results, the lake will be lowered—

	Inch per day.
By evaporation	0.20
By lockages	.0157
By leakages at locks and sluices	.0157
By leakages at Ochoa Dam and the embankments	.0661
Total for one day	.2975

Or a total for sixty days of 17.85 inches, equal to 1.49 feet, say 1.5 feet.

This is the amount the lake would be lowered in sixty days with no inflow and no discharge except requirements for canal purposes. If at the end of this period the lake is to be at 110 feet, it must be 1.5 feet higher at the beginning, or 111.5 feet. As no allowance has been made for inflow into the lake during this period, this may be too high. On the other hand, the dry season may be longer than assumed, and the estimate too low. Colonel Childs arrived at the same reduction of level during the dry season by a different line of reasoning, and the result is probably near the truth. More exact data are needed, and can be obtained readily, at little cost, in connection with other investigations recommended in this report.

The low-water slope from the lake to Ochoa, after the completion of the Ochoa Dam, is assumed by the company at three-fourths of an inch per mile, or, in round numbers, 4 feet for the entire distance. With the water surface raised to so great a height the cross section of the river channel will be greatly increased, and the velocity required to pass the ordinary low-water flow of, say, 10,000 cubic feet per second, will become so small that hydraulic formulæ can not be depended upon for precise calculations of slope; the slope will be so flat, however, that a large proportionate error is of no importance. Calculations indicate that at extreme low water the total fall from the lake to Ochoa will not be more than two-tenths of a foot, and probably considerably less; the river becomes really an arm of the lake and with the same elevation. Since the lake is to be maintained at a minimum elevation of 110 feet, and since, in order to secure this, the outflow must be checked on the approach of the dry season, when the lake is 1.5 feet higher (approximately), the weirs on the San Carlos Ridge must be so arranged that their crests can be raised to 111.5 feet or more.

The elevation of water surface against the dam at low stages of the lake being 110 instead of 106 feet, the difference will cause a notable increase in the volume of the embankments and in the lift of the chain of locks between the Caribbean and the summit level.

The control of the discharge of the surplus water is a matter of no less importance than the maintenance of the summit level, but the data necessary for its intelligent consideration are almost wholly wanting. The amount of water to be dealt with, either during the year or during high floods, is unknown. The annual rainfall is not known at any point between Ochoa and the west shore of the lake. The subject is so vital, however, that an attempt must be made to cast a little light upon it with such data as can be had, and an estimate will be made first of the annual discharge.

The area of the drainage basin of Lake Nicaragua is taken at 8,700 square miles; of the lake itself, 2,700 square miles; of the drainage basin of the San Juan above Ochoa, 2,250 square miles. The annual rainfall in the lake basin is taken at 80 inches; run off, 40 per cent; evaporation from the surface of the lake, 40 inches per year. In the river basin the annual rainfall is taken at 150 inches; run off, 60 per cent. These figures, which may all be considerably in error, give the following results and averages in cubic feet:

Basin.	Received by lake and river.		Loss by evaporation.		Discharge.	
	Per year.	Per second.	Per year.	Per second.	Per year.	Per second.
Lake Nicaragua	947,865,600,000	30,057	250,905,600,000	7,957	696,960,000,000	22,100
San Juan River, between the Lake and Ochoa	470,448,000,000	14,918	Neglected.	....	470,448,000,000	14,918
Discharge at Ochoa.	....	....	....	....	1,167,408,000,000	37,018

The river has never been gauged at a flood stage. A gauging was made by the company May 21–25, 1888, in the vicinity of Ochoa, but it is not known precisely where, and the water surface was not referred to the company's bench marks. The highest recorded stage at Ochoa occurred January 7, 1888, and its height was noted. If the difference of stage at Ochoa at this date and at the date of the gauging were known, a rough approximation could be made to the flood discharge by a comparison of cross sections. From December, 1887, to January, 1890 the company kept a river gauge record at San Francisco Island, 12 miles below Ochoa, and if this were available an indirect and approximate comparison could be made between the two stages and the flood discharge deduced. Unfortunately the record for the first seven months, including the highest stage and lowest stage observed, is missing. By other data, however, the Board has been able to establish a comparison, which leads to the conclusion that the flood discharge January 7, 1888, was about 125,000 cubic feet per second. The company's gauging, which, it is stated in the Chicago paper, establishes 42,000 cubic feet per second as "high flood," represents in fact only a moderate flood; probably not much greater than the mean discharge.

During the inspection of the river by the Board, in May and June, 1895, it was learned that at Machuca Rapids the flood of November, 1893, rose considerably above that of 1888. While it may be that the San Carlos was not correspondingly high, it does indicate that the highest flood may be considerably greater than that of 1888, and the Board is of the opinion that until more reliable data are obtained the maximum discharge at Ochoa should not be estimated at less than 150,000 cubic feet per second.

Such a flood could only result from heavy rains over the entire river basin, in conjunction with a high lake. The extreme floods are of short duration, but a moderately high stage may be maintained for a considerable time. Sluices, or weirs with adjustable crests, must be provided in the San Carlos embankment line for the quick discharge of these floods. More precise data as to the extent of the floods are necessary before the dimensions of the weirs or sluices can be fixed, but for the purpose of entering the item in the estimates the Board has assumed weirs with a crest length of 4,000 feet. A weir of this length with a head of water of 4.5 feet will discharge 130,000 cubic feet per second, and this provision may possibly suffice.

Whatever the crest length of weirs may be, provision can be made for drawing off such amount of water as may be necessary by placing movable dams on them. The water on the upstream side can be kept at any desired height. Thus the discharge of the surplus water at the weir can be regulated, but the regulation of the lake itself offers difficulties, and the matter is so important and has been so completely overlooked that considerable attention must be given to it here.

During the visit of the Board to Nicaragua high-water marks were shown on both sides of the lake which fix its high stage at 111 feet above mean tide. The variation in the surface of the lake from ordinary low water, which may be taken at 102, to high water at 111 is 9 feet. No such variation can be permitted with the lake maintained at the summit level elevation of 110 feet as a minimum, because much valuable property on the west side of the lake would be drowned out, and for this reason it is probable that a higher stage than 113 feet will be inadmissible. This permits an extreme range of only 3 feet, and it may be doubted whether the regulation of the lake level within so narrow a limit is possible.

During the rainy season the water is received into the lake more rapidly than it runs off, the surplus being stored in the lake, causing it to rise. The only way by which an equal rise can be prevented after the construction of the Ochoa Dam is by increasing the discharge through the San Juan during the rainy season. An increase in discharge can only be produced by an increase in cross section or an increase in velocity in the outlet channel. The water of the lake must be carried off more rapidly during the wet season after the construction of the dam than under present conditions. The increase in discharge must be very large, and it must be determined whether under the new conditions the capacity of the outlet channel will be sufficient to meet the greater demand upon it.

The data required for a solution of this problem are the amount of water received by the lake and the capacity of the outlet.

The amount of water received by the lake in a given period could be determined from the following data:

(1) The discharge during the period.
(2) The area of the lake.
(3) The difference in elevation at the beginning and end of the period.
(4) Loss by evaporation during the period.

All of these can be ascertained exactly by observation. During the rainy season the evaporation is probably unimportant and can be neglected.

The flow into the lake could be determined also by means of the rainfall, and the following data would be required:

(1) Area of lake.
(2) Area of watershed.
(3) Average rainfall in basin.
(4) The run off, or proportion of the rainfall which passes into the lake.

These data are less capable of exact ascertainment than the former, and, therefore, an estimate based on them is not so reliable; on the other hand, they may, in circumstances like the present, afford a rough approximation to a result which, for lack of data, can not be reached in any better way.

In the absence of better data this method will be used here in order to arrive at a general idea of the problem.

The following assumed data are believed to be conservative. The area of Lake Managua and its watershed are not included, for the reason that periods of several years have been known during which there was no visible outflow from that lake. It is possible that during very rainy seasons the amount contributed by Lake Managua may be considerable, and it may be that subterranean channels exist through which the lake discharges constantly:

Area of Lake Nicaragua, 2,700 square miles, approximately.

Area of watershed, 8,700 square miles, including lake. This may be considerably in error, but is taken from the best maps available.

Rainfall, 80 inches per year. It will be assumed that 25 per cent may fall in one month, 45 per cent in two months, 60 per cent in three months, and 70 per cent in four months.

Runoff, 50 per cent of rainfall.

With these data the amount received by the lake in different periods is calculated, and also the net rise in the lake, with various rates of discharge.

Amount of water received into lake.

	Cubic feet.
In one month, with 25 per cent of the annual rainfall	264,844,800,000
In two months, with 45 per cent of the annual rainfall	476,720,640,000
In three months, with 60 per cent of the annual rainfall	635,627,520,000
In four months, with 70 per cent of the annual rainfall	741,560,440,000

The rise in the lake is retarded more or less by the discharge through the San Juan.

The following table gives the net rise, with several rates of discharge:

	Rise of lake with discharge of—		
	25,000 cubic feet per second.	50,000 cubic feet per second.	75,000 cubic feet per second.
	Feet.	*Feet.*	*Feet.*
In one month	+2.7	+1.8	+1.0
In two months	+4.6	+2.9	+1.2
In three months	+5.9	+3.3	+0.7
In four months	+6.4	+3.0	—0.5

It appears from the table that if the assumed data are correct, the lake can be controlled within the required limit of 3 feet with a discharge of a little over 50,000 cubic feet per second. The actual discharge from the lake at the highest stage, under present conditions, has not been supposed to be anything like this.

If a greater discharge than the present maximum is to be obtained, it must be produced, as before stated, by an increase in cross section or an increase in velocity in the outlet channel. Within the limits of the present case the velocity can not be materially increased without an increase in slope. This can not be obtained without a large and costly deepening of the river bed in the vicinity of Toro Rapids, so that the question of increased discharge practically narrows down to that of increased cross section.

The height of the lake, when this average discharge of 50,000 cubic feet per second is to be maintained, will vary from 110 feet, the minimum, to 113 feet, the assumed maximum; the average will not be far from 112, or only 1 foot above the highest stage now known, so that no great increase of cross section will be produced by the additional height under the new conditions. Another increase, somewhat greater in amount, will result from the excavation to be made from the lake to Toro Rapids for a 30-foot navigation.

It may be that the discharge of the lake at high water is much greater than has been supposed, and it may possibly approach nearly the amount of 50,000 cubic feet per second calculated as necessary under the new conditions.

The governing stretch of river, as regards the outflow of the lake, is between the lake and the foot of Toro Rapids, but affected in some degree by the natural weirs at Castillo. Below the latter point the section of the river will be so much greater after the construction of the Ochoa Dam that its capacity will be ample, with very small slopes, for the largest discharge.

If the variation of the level of the lake can not be limited to 3 feet, and if it is inadmissible to raise it above 113 feet, then it is impossible to maintain it at a minimum of 110 feet. Every foot of reduction in the minimum will cause a large increase in excavation throughout the entire summit level, including the costly work in the San Juan River and the east and west divides. The calculations just made suggest much uncertainty about this, but they are based wholly on assumptions as to the discharge of lake and rainfall, which may be far from the truth; the ascertainment of the facts by continuous observations for not less than one year and including at least one high stage of the river, is absolutely indispensable. A single year's record might prove misleading if the high stage were of unusually short duration, since it is the total quantity of discharge that is required. It is to be regretted that the canal company has no recorded observations of the lake level or other data relating to its regulation for the eight years since it began work in the country. The matter is of such vital importance that observations ought to have been made continuously during the entire period.

The discharge of the San Juan must be regulated by weirs or sluices in the San Carlos embankment; that from each minor basin (the Florida Lagoon, San Francisco Basin, etc.), by its own sluice or weir, the water level in the minor basins being made to conform to that in the San Juan immediately above the Ochoa Dam, so as to avoid currents through the narrow connecting channels.

The data do not exist for determining the discharge for which the weirs in the San Carlos Ridge should be proportioned, or for calculating the fall from the lake to the weirs during the high-water season, which must be taken into account in fixing the elevation of their crests. It is probable that in order to secure the requisite velocity through the governing section the water surface at the San Carlos weirs must be drawn down during the wet season much below the level required during the dry season. It is essential to determine exactly how much this enforced reduction of level must be before the grade of canal bottom can be fixed between the San Juan River and the summit lock at the east divide or in the excavated channel in the San Juan itself.

The whole problem of the regulation of the summit level, the establishment of grades in the various excavations and structures within its limits, and even the practicability of the company's project without much modification requires the collection of a large amount of information before it can be solved. The scope of the investigations necessary is treated more fully elsewhere.

EASTERN DIVISION.

GREYTOWN HARBOR.

The San Juan River, draining a total area of some 15,000 square miles, most of which in times past has been subject to intense volcanic action, and is still affected by the heavy rainfall of that region, has brought down in course of time an enormous volume of sand, in part directly emitted by volcanoes, and in part derived from the disintegration of igneous rocks and washings from the clay, and has built up in the Caribbean Sea a flat and swampy delta of great extent, heavily forested and containing many lagoons and tortuous channels of varying dimensions.

The main river forks about 18 miles from the coast, and discharges through several channels, of which the Colorado is the principal, and the second in size the Lower San Juan, which reaches the sea at Greytown in the angle where the fan-like projection of the delta meets the coast line stretching to the northwest.

The earlier maps show the bight at Greytown as a capacious harbor, protected from northeast winds by the delta projection, and with ample depth and area.

It is now a lagoon shut off from the sea, and has ceased to exist as a harbor for seagoing vessels. The gradual closing of the harbor, between 1832 and 1862, by the movement of the outer beach stretching westward across the entrance in the form of a narrow sand spit to connect with the west shore line was a serious drawback, both to the maintenance of a freight and passenger route across the Isthmus via the San Juan River and Lake Nicaragua and to the project for the construction of a ship canal over the same line.

Various causes were assigned for the destruction of the harbor, and various means suggested for its restoration. It was usually considered that the river had most to do with the matter, but opinions differed as to whether the detritus brought down in flood or the diminishing power of the stream, which had become evident in the reduction of its navigable capacity, to carry off the accumulations driven shoreward by the sea was responsible.

The remedy, from one point of view, was to cut off the river altogether; from the other, to strengthen it by closing the other outlets, which discharge 90 per cent of the volume of the main stream.

It is probable that the causes are far more general, and that if the delta, which is almost unexplored, were fully mapped, its numerous interior lagoons and water courses traced, and its history thus ascertained, the original formation and final destruction of Greytown Harbor would appear simply as a recent example and repetition of the history of many others.

The delta sands forced seaward in great volume by a powerful current in opposition to the trade winds and seas would be distributed lengthwise of the coast, and from time to time an area of sea floor would be at first cut off, and by continuance of the littoral movement be ultimately inclosed, and a lagoon formed beyond which the coast line would continue to advance so long as the supply of sand was in sufficient quantity. The parallel lines of long and deep lagoons lying inside the Colorado mouth are typical of this action.

In the case of Greytown, the sands that destroyed it came not from the Lower San Juan, which for a long time probably had ceased to carry down any considerable amount, but by the action of the east-northeast seas striking the coast at an angle and driving the light volcanic detritus westward along the beach.

Comparison of authentic charts of various dates will make this clear, and it is due to Professer Mitchell, of the Coast Survey, to say that in his paper contained in the Coast Survey Report for 1874 the true history of the case is for the first time suggested, although the important fact of the wasting of the outer beach to the eastward of the harbor escaped observation.

So far as the future is concerned, there is reason to believe that the movement of sand by river action has greatly diminished and will so continue.

Volcanic activity in the interior of Nicaragua and Costa Rica seems to have exhausted itself; there are no longer eruptions of volcanic sand; and while the Colorado River is still a turbid stream in flood and the San Carlos branch of the San Juan a torrential stream, it is probable that the detritus to be yet delivered is small as compared with what has in ages past been brought down.

The oldest chart of any value for purposes of comparison is that of 1832 by Captain Peacock, the master of a British vessel. The harbor is shown as furnishing safe and ample anchorage for vessels of any draft, with an entrance nearly 2 miles in width unobstructed by any bar, and gradually deepening off into the Caribbean Sea. It was, in fact, at that time a portion of the ocean floor inclosed on three sides and with a large area of 30 feet depth open only between north and north-northwest.

The history of its destruction is graphically indicated by the additions to the 1832 chart of the successive positions occupied by the sand spit, between 1832 and 1859, in its westward advance across the entrance which resulted in total closure soon after 1861, at which date the channel under the beach had been reduced to a width of 300 feet.

The harbor then became a lagoon, generally with a shallow and variable opening through the sand spit, maintained by the outflow of the river, but at times completely closed and in need of artificial cutting to rid itself of the rising accumulation of river water.

The next chart is that by Captain West, of the Coast Survey, in 1865.

Endeavor has been made to effect a common orientation of the two, but uncertainties of scale and compass bearing, and the absence of definite common points make this difficult, and it may well be that the extraordinary changes indicated by a comparison of these charts are much greater than actually occurred; but the general nature and progress of these changes is fully confirmed by subsequent maps, and since absolute quantities need not be computed the comparison is of value.

The first thing noted on the 1865 chart is the shrunken condition of what was once the harbor. A single 30-foot sounding represents the broad expanse of that depth on the Peacock chart, and this reduction has been effected apparently from every direction by the recession of the sand spit by an extraordinary advance of the south and west shore line, and by the growth of the river delta.

Synchronously with these changes there has been an extensive cutting away of the shore line adjacent to the Harbor Head Lagoon northeastward from Greytown, and this is balanced by a roughly equal accumulation along and consequent advance of the west shore line, amounting to some 1,000 or 1,500 feet. The absence of off-shore contours on the 1865 chart prevents what would have been a valuable comparison of their positions at the two dates, supplementing those of the shore lines.

The succeeding chart is that of 1872, by Lieutenant Miller, U. S. N., made in connection with the Lull expedition.

The area of the Greytown Lagoon is still further diminished, and the maximum depth is reduced from 30 to 19 feet.

Comparison of the coast line shows an advance of the west line of 500 feet since 1865, and, so far as the northeastward shore line is platted, the wasting action in the vicinity of Harbor Head has continued.

The succeeding chart is that of 1884, by Passmore and Climie.

Comparing with 1872 it does not appear that the northeast coast line has materially altered; but there has been a significant deepening of the sea floor off Harbor Head that has moved the 6 and 8 fathom contours shoreward. In other words, the shore erosion has been made up from the ocean bed, indicating wave action at those depths. The corresponding advance of the westward coast line has continued to the extent, approximately, of 500 feet.

The shifting and unstable nature of the outer beach from Harbor Head westward is well indicated by all these charts, which show it continuous or broken at several points at the different dates.

In the Greytown Lagoon there has been no particular change, and there is reason to believe that the discharge through the Lower San Juan into the lagoon has had much less to do with the diminution in harbor area and depth than the incessant changes that have taken place in the outer beach under the influence of occasional strong northers and the milder but persistent east-northeast trade, both tending to drive the beach sand into the quieter water of the lagoon.

The next chart is that of 1888, by Ensign Maxwell, U. S. N.

In 1884 the Harbor Head Lagoon was closed from the sea and the Greytown Lagoon open, through numerous breaks in the beach. In 1888 the conditions are reversed. Harbor Head is freely exposed and Greytown completely barred.

The wasting action near Harbor Head has continued, unaccompanied, however, by a corresponding advance of the westward shore line, but this is in part accounted for by the great accumulation of sand in front of Greytown Lagoon and a notable diminution of depth in the vicinity of the beach, both inside and outside.

Comparing the sea contours, it is observed that off Harbor Head they are substantially unchanged, but in front of Greytown the 4-fathom curve of 1888 touches the 6 of 1884, and the 6 of 1888 has filled in the sea angle of the beach and moved offshore by a maximum of 3,000 feet.

The final chart is that of 1895, of which the shore line was surveyed by the Board and the offshore soundings made by Lieutenant Lyman and other officers of the U. S. S. *Montgomery*.

In front of Greytown Lagoon the chart shows the effect of the canal company's construction intended to secure an entrance, both in the prompt advance of the shore line to the outer end of the pier on the east side and the reaction to leeward of this work represented by the overhanging spit and the local recession of the shore line. Of this construction further particulars will be given later.

Nothwithstanding the temporary interruption to the westward movement of the beach sands due to the pier, the west coast line has built itself out some 250 feet since 1888, and the 4-fathom curve has moved seaward about twice as much. The 6-fathom curve has come in about the same, and the 8-fathom curve is unchanged.

The comparative stability of this 8-fathom curve throughout the continual changes that have taken place is a matter to be noted.

Northeast from Harbor Head the offshore contours all evince a disposition to approach the beach, the wasting in the interval, 1888 to 1895, having affected the deeper areas instead of the shore line.

To sum up the changes that have taken place as indicated by the charts, those of 1872 and 1895 may be compared.

To the north and northeast of Harbor Head the shore line has wasted 1,000 feet and been followed up by the sea contours to an equal extent.

Northwest of Greytown the beach has been solidly built out parallel with itself and normal to the direction of the prevailing winds and sea for 800 feet, the positions of the old wrecks indicating what were probably the 2-fathom contours at their several dates. The 2 and 4 fathom contours have moved seaward in proportion with the shore line. The 6 and 8 fathom contours have not materially changed in position.

In front of Greytown Lagoon the beach has built out northward 1,000 feet to the end of the canal company's pier, and is now filling in the angle to the westward. About 8,000 or 9,000 feet east of the pier appears a neutral point about which the waste and fill have approximately balanced, where the shore line and sea contours are practically unchanged, and where deep water is soonest reached from the shore line.

It is evident that there has been an enormous movement of sand from east to west, and that the resultant action has been large erosion near Harbor Head and corresponding accretion westward of the Greytown entrance.

None of the charts that have been made has extended far enough to the east and south toward the Colorado entrance to enable any judgment to be formed as to how far the wasting action at Harbor Head has continued in that direction, where the westward movement of the beach sand begins, and if the actual waste at Harbor Head is the resultant of an excess of erosion over supply from the southeast. The extraordinary arrangement of lagoons near the Colorado mouth is conclusive, however, that the initial movement is beyond the Colorado, as these parallel lagoons were evidently successive portions of the river which had been overlapped by littoral sand movements from beyond.

For a satisfactory discussion of the whole subject, the observation of movements of beach and contour lines should cover the whole distance to and beyond the mouth of the Colorado, and to the north and west, to include at least the valley of the Indio, 9 or 10 miles above Greytown, as the indications are that this river, which drains a large area of heavy rainfall, is working its way southward toward Greytown.

On approaching the beach, the Indio turns sharply to the right and flows parallel with the shore for nearly 5 miles before reaching the sea, from which it is separated by a narrow sand spit. The position of the mouth is not permanent, nor is it at this time as far south as it has been. From time to time, under pressure of floods, the current cuts a new outlet higher up, which again gradually works southward.

The importance of this action is due to the fact that it shows the southeasterly littoral sand drift toward Greytown, supplementing the westerly movement from Harbor Head to fill up the reentrant angle in which the present entrance is situated.

It is to be presumed that, the working forces remaining the same, though possibly in less amount, the resultant action will continue, the sands of the east beach will move westward and of the west beach southward, and accretion follow erosion, wearing away the prominence and building out the bight, until the convexity of the coast line has been approximately straightened by the filling up of the angle in the immediate vicinity of the present entrance to the Greytown Lagoon.

The scale upon which these movements take place is such that time is needed to effect them, but it seems safe to conclude that the endeavor to construct a harbor entrance for the canal immediately adjacent to the head of the bight, where the maximum filling action from both directions must take place, will involve engaging at once in a perpetual contest with forces of great power and persistence at the point of application of their resultant effort.

On the prolongation of the company's pier the 6-fathom contour is over 1,500 feet distant from shore, the 7-fathom 4,000 feet, and the 8-fathom about 8,000 feet. It is certainly to be anticipated, in case of an attempt to build out on this line, that the beach will promptly follow over the comparatively flat bottom, and the ultimate expenditure required for pier extension and dredging reach large amounts.

On the other hand, the Harbor Head Lagoon has some evident advantages over Greytown Lagoon as a canal and harbor entrance in its greater remoteness from the western shore angle and greater proximity to the deep sea contours, but it may be apprehended that the waste and mutability of the outer beach and the greater exposure to wind and sea may involve hazards which it would be better to avoid.

The Board is, therefore, of opinion that the Greytown entrance is inadmissible and the Harbor Head entrance inexpedient, and that the best results will be attained by locating the entrance approximately halfway between the two, in the vicinity of the neutral point previously referred to.

At this point the 8-fathom contour is only 2,000 feet from the shore line, and the maximum results in sheltering the entrance can be had with the minimum length of protecting works, while the alignment of these works can be so adjusted as to reach deep water about normal to the shore line, bearing a little west of north, and furnishing protection from the prevalent winds and seas coming from about east-northeast.

CONSTRUCTIONS PROPOSED BY THE BOARD.

The preliminary views of the Board are indicated on the chart of 1895.

The east pier, the main work, curves off shore, with a total length of 3,000 feet from the inner end to the 7-fathom contour to hold and protect the entrance. The comparatively still water in the lee of the main work would enable the waves to swing rapidly around, with a reacting effect on the shore to the westward, which would tend to drive sand into the harbor entrance. The west pier and inner walls, with a total length of about 2,000 feet, are designed to prevent this and furnish partial shelter for tugs and other vessels wishing to lie near the entrance.

Measuring across from the outer end of the west pier, the width of the entrance is 600 feet, and a vessel entering will be under the lee of the main work and partially sheltered from the sea before reaching the narrower passage.

In order to open an entrance as speedily as possible and provide harborage for vessels bringing construction plant and material for beginning work on the line of the canal, a temporary pile pier should be built on the line of the east pier, in which it would ultimately be buried. The pile pier would have a length of about 1,500 feet—enough to furnish cover for a dredge to begin operations, secure the necessary depth of entrance, and cut back into the Greytown Lagoon.

The most convenient point at which to procure the rock filling for the pile pier is a quarry about 3,000 feet from Lock No. 1. The opening of this quarry would be in a sense dead work, but the harbor is a necessity, and could not await the opening of the divide cut, whence the remainder of the stone needed for harbor construction would be taken.

It is to be expected that the outer angle between the east pier and the shore line will eventually fill with sand from the westward movement of the beach, but a considerable time will be required to reach the outer end near the 8-fathom curve, and a very prolonged period before the filling in of the ocean floor could injuriously affect the entrance depth.

The gradual accumulation against the pier would tend to diminish the waste of the beach to the eastward, and should this prove later to be in such quantity as to be disadvantageous, the surplus material from the divide could be used to check it by building short groins or jetties.

From the entrance a straight connecting channel 5,000 feet long, with a bottom width of 200 feet and a low-water depth of 30 feet, is to be dredged directly toward the deepest part of the Greytown Lagoon, which will form the harbor to be dredged to 30 feet at low water, with an area of 237 acres. Thence the canal proper will start westward toward the divide.

The adoption of this plan will involve an abandonment of the existing two-thirds of a mile of canal that has already been partially excavated, but the cost of this is not material, in view of other and more serious considerations.

CONSTRUCTIONS BY THE COMPANY.

The pier constructed by the canal company for the purpose of securing an entrance, as built December, 1889–May, 1893, is shown on the chart of 1895.

The length of this pier as proposed is variously stated. In Mr.

Menocal's Chicago Congress paper it is given as 3,000 feet, in the final report of 1890 as 1,700 feet, and in the scheduled estimate as 900 feet. Nine hundred and thirty-seven feet was the actual length when construction was suspended in 1893. As built, it is 42 feet wide, consists of six longitudinal rows of piles, capped and tied, and carries a railway track. The filling is partly of rock from a quarry near Silico Lake, and partly of concrete.

The effect of this pier in suspending westward drift of beach sand and creating still water behind it enabled the surf to cut away the beach and make an opening which the outflowing current from the lagoon presently deepened to about 6½ feet.

This depth permitted dredges drawing 7 feet light to be dragged in over the bar with the aid of the sea, and by means of the dredges the entrance was then deepened to 12 or 14 feet, which, however, could not maintain itself without artificial aid.

The harbor was not at any time available for other than comparatively light-draft vessels, and but three or four used it.

One schooner with a load of timber for the company was wrecked in trying to enter, and vessels bringing cargoes of material were partially or altogether discharged by lighters.

The beach rapidly followed out the pier extension, and as soon as the end of the pier had been reached the sand poured by and at once filled up the deepened entrance.

The pier timber and piling were creosoted with 16 pounds of wood oil to the cubic foot, but this proved unavailing as a protection from the teredo, and when examined in May, 1895, the piles near the outer end were found to have been badly eaten, and many on the channel side had disappeared. Much of the timber also was badly decayed. The teredo is very active in these waters, and excessive humidity and uniform high temperature are extremely trying to wood unless housed or well painted, and its destruction when exposed is very rapid.

The cost of the pier as constructed was $164,507, or at the rate of $175 per running foot, according to figures furnished by the company.

A considerable amount of harbor dredging has been done by the company with its own plant, supplementing the endeavor to open the entrance, provide harborage and access to the company's buildings, shops, etc., constructed 2 and 3 miles northwest of Greytown, and to begin work on the canal.

The material excavated was almost entirely volcanic sand, similar to that of the beach. This sand is dark in color, rather coarse, has a specific gravity considerably less than that of ordinary sea sand, and when submerged is readily acted upon by waves and currents.

When piled in heaps it forms a porous mass through which the torrential rainfalls descend with surprisingly little effect upon its contour, even though the slopes be steep. This feature was noted both in the mounds of dredgings near the entrance and in the canal banks, where the sands dropped from the dredge chutes still stood seemingly undisturbed since they were put there.

The portion of canal work done by the company consisted of a single cut with an elevator dredge for a distance of 4,350 feet, with a width of 167 feet and a depth of 16½ feet, followed by an adjoining cut for about half the distance. The width of the two cuts was 279 feet.

The excavation was mainly within a funnel-shaped area, where the canal section proper widens into the harbor. The dredgings were left, as deposited from the spout, immediately upon the edge of the excavation, and would require rehandling to place them at a proper distance from the banks.

The total amount of dredging in canal and harbor, as stated by the company, was 727,861 cubic yards, and the total cost $80,000 in round numbers, or at the rate of 11 cents per cubic yard, which represents the net cost of dredging in very favorable conditions, and with the company's plant, without charges due to first cost and maintenance.

The buildings erected by the company along the beach are on a liberal scale, of good design and construction, and consist of storehouses, barracks, and headquarters buildings, quarters for officers, hospitals, shops, etc. All are of wood imported from the United States, and in fair preservation, although in a state of comparative neglect, where if needed repairs, painting, etc., are not speedily attended to the buildings will be seriously damaged. In several cases the roofs are of galvanized iron, which is also used for many of the buildings in Greytown. This material shows remarkable durability under exposure to the local climatic conditions.

A large amount of property of various kinds lay out of doors and in an advanced condition of decay—numerous steel boats and launches, hulls and machinery rusted through; a pile of 8-inch spiral riveted pipe, intended to bring water from a reservoir to the barracks and quarters; spare shears for the dredges; two or three tugs and small steamboats, past all service; several scows and lighters rotten and sunk. The five dredges bought by the company from the Panama Canal dredging contractor lay in the harbor on the bottom uncared for, with rusted machinery and woodwork dropping. Three locomotives under cover are probably unserviceable. The machine shop, having been used to a certain extent by the river navigation company for occasional repairs to their vessels, was capable of service, but, with the exception of the large buildings, little else could be considered as representing any value.

In case of resumption of work at the harbor, it might be practicable to construct one serviceable dredge by building a new hull and taking out of the present dredges such machinery as would answer the purpose and be found usable. Should this prove to be practicable, the construction could be begun from inside without waiting for the opening of an entrance through the beach.

While giving a brief account of the plant and constructions at Greytown Harbor, where all the work connected with the actual canal building was done, it will be convenient to include the railroad which extends inland for a distance of 11⅓ miles along the line of the canal to between the sites of Locks 1 and 2.

The Board made a trip over the road on a hand car propelled with poles, and the results were of interest and value.

The single track is standard gauge, laid with 60-pound steel rails, from Pittsburg, and 2,464 ties to the mile, and was built between May, 1890, and February, 1892.

The ground covered is flat and swampy for the greater part of the distance, and across the wetter portion the roadbed was formed by first cribbing roughly, then laying a temporary track and filling with sand, most of which was brought from the canal cut at Greytown. Most of this work was done by men working up to their waists in water.

Notwithstanding the exposure to the immense rainfall, the roadbed when examined was found in fairly good condition, and the rails gave little evidence of corrosion, but the ties were gone. Those first laid near Greytown were of North Carolina pine, creosoted with 12 pounds of wood oil to the cubic foot, and were apparently about in the same condition as would be that of uncreosoted ties laid for three or four years in the States. Farther out, pine ties from Bluefields, not creosoted, were much decayed. The remainder, of native timber, were entirely rotten. With a few exceptions all the ties must be replaced before the road can be used.

Four and one-half miles out is a clay fill standing well with little indications of wash and leading to the bridge crossing the connection between the Benard Lagoon and the San Juanillo River.

The bridge is a pile structure of ordinary type, about 125 feet long, 4 piles to the bent, braced and capped. The noticeable peculiarity of the bridge was that it had been stayed both up and down stream with wire ropes secured to trees. Upon inquiry it was learned that the piles had been driven through 70 feet of soft mud. As the locality in question is within a few hundred yards of the lagoon through which the canal line passes, the subsurface conditions, if continued in the lagoon, are very unfavorable features for canal building.

Beyond the bridge crossing is the first clay cut, and farther on both cuts and fills are numerous.

The cuts have heights up to 20 feet, with slopes from vertical to 45 degrees, and in most cases stood with an extraordinary stability under the tropic downpour. At several the original tool marks were still visible, both pick and steam shovel. In several others there had been slides, but none of great extent. The ditches were generally clean, and in but few points had the wash reached the rail. The surface of the cuts was in some cases protected by vines, but in most was quite bare unless for a minute lichen.

As these clay cuts had been exposed for over three years to the severest rainfall of record on this continent, and were found in better condition on the whole than an exposure in the United States for a single winter would have left them, it is evident that the absence of frost more than balances the tropic downpour, and for the materials in question constructions can quite as safely be designed as in the United States.

A train of flat cars standing at siding was nearly covered with vines and creepers and the woodwork far advanced in decay. On the other hand, the natural growth in the roadbed was unexpectedly slight, although in two or three cases the canebrakes had invaded the track.

On the whole, taking into account the condition of the sand dumps at Greytown and of the clay cuts and fills on the line of the railroad, it is evident that the heavy rainfall is not necessarily as formidable an obstacle to outdoor constructions as might be supposed, although the slight works in question must not be too confidently accepted as safe precedents for much heavier constructions, and, with work in clay, an accumulation of water must always be guarded against.

GREYTOWN HARBOR TO OCHOA.

A preliminary location of the line from Ochoa to Greytown adopted by the company was made by Mr. Menocal in 1885, and the final location is described in his report of January 31, 1890. The route follows a nearly direct course from Greytown Harbor to a point on the San Juan River, 3 miles below the mouth of the San Carlos, crossing the east divide by way of the valleys of the Deseado on the eastern and the Limpio on the western slope.

The governing feature of the project is the extension of the summit level from the lake to the east divide. This is to be accomplished by a long line of dams and embankments described elsewhere in this report.

The project offers several important advantages.

First. A considerable saving of distance will be made, estimated by the company at 12 miles.

Second. Navigation will be facilitated by the formation of basins in the valleys of the Chanchos, Nicholson, and San Francisco rivers, and in the Florida Lagoon.

Third. The drainage of these streams will be received in the basins and currents avoided.

Against these advantages are to be offset the risks inherent to the Ochoa Dam and the large and numerous embankments.

GREYTOWN HARBOR TO LOCK NO. 1, 9.30 MILES.

The first location was a straight line which cut across a bend of the San Juanillo, and required a new channel for that river 7,000 feet long. A few hundred feet to the northward, opposite the middle of the section, lies the depressed area known as the Benard Lagoon. In order to avoid the San Juanillo, and to reduce the amount of excavation, the line, by a later location, is thrown northward into the lagoon, which is nearly 3 miles across. A short curve is introduced and the two lines meet at Lock No. 1.

The ground is a swamp nearly the whole distance; the general elevation is not more than 5 feet above mean tide until the Benard Lagoon is crossed, then rises gradually to 16 feet at the foot of the hill in which Lock No. 1 is located.

The swamps are drained by a network of streams, connecting with the Indio on the north and the San Juan on the south, and the amount of water bordering the line is too large to be received into the canal. It will therefore be necessary to raise the canal banks above the highest water level in the swamps; and the bed of the Benard Lagoon is supposed to be mud to a great depth, in which it will be difficult to build banks. If this prove to be the case, a return to the former location may be required, with an addition to the amount of excavation.

The company proposes to make the bottom width in this section 120 feet, the depth to be 28.2 feet below mean tide in Greytown Lagoon, the side slopes 3:1 in sand and 1½:1 in clay. This width is adopted with a view of constituting the section an extension of the harbor, in which vessels can lie or pass each other. The depth proposed, which is 1.8 feet less at mean tide or nearly 2.8 feet less at low tide than the general depth in the canal, is understood to be temporary, the full depth of 30 feet to be obtained, after the opening of the canal for navigation, by the use of the maintenance plant.

The Board believes that the estimates should cover the cost of the work completed to full depth, and that the width proposed is insufficient for passing and more than enough for the movement of single vessels. The estimates have been modified, therefore, to provide for a general width of 100 feet, with three passing places, 180 feet wide, for a length of 600 feet, and an increase of depth to 30 feet below low water in the Caribbean. The several changes nearly balance and involve little additional cost.

In the dredging done by the company for a short distance from Greytown Lagoon westward the material was a coarse sand, similar to that of the beach; this material continues westward about 3 miles, and is followed by clay and the mud of Benard Lagoon; west of the lagoon the material is clay, overlaid in places by a few feet of mud. All this material can be excavated readily by dredging, excepting possibly the deep mud in the lagoon, which can be avoided by a change of line.

LOCK NO. 1 TO THE EAST DIVIDE, 6.65 MILES.

The tide lock (No. 1) is located in a hill which projects from the north into the valley of the Deseado. It is to have a lift of 31 feet from mean tide, raising the water surface about 15 feet above the valley floor.

A dam is required across the valley having a crest length of 1,450 feet, and a height of 23 feet above the valley floor, or 32 feet above the bed of the Deseado; provision is made for the regulation of the upper level by a concrete masonry sluice with two openings, each 20 by 25 feet, and two weirs of 100 feet each, placed in depressions in the flanking hills.

In addition to the above, four small embankments, of an aggregate length of 660 feet, are required in saddles between the hills to complete the line by which the upper level is to be maintained.

A canal is to be excavated the entire distance of 1.33 miles between Locks Nos. 1 and 2, with one crossing of the Deseado, which will have to be diverted. The flood discharge of the stream is not known, but is probably 3,000 or 4,000 cubic feet or more per second. Its diversion and control will be a matter of considerable expense, for which no special provision is made in the estimates.

Lock No. 2 is located in a hill on the south side of the valley, and has a lift of 35 feet. A change to a hill on the opposite side has been suggested, and, if made, the diversion of the Deseado above referred to would not be necessary. The same provision is made of weirs and sluices as at Lock No. 1. In addition to these, a dam and two embankments will be required to close the valley, having a total crest length of 2,030 feet; the greatest height will be 48 feet above the valley floor, or 69 feet above the bed of the Deseado.

From Lock No. 2 to Lock No. 3, a distance of 4.55 miles, the line for the first 2½ miles passes through a basin formed by the dam and embankments at Lock No. 2, followed by an excavated channel for the remaining distance, in which several diversions of the Deseado, not specifically estimated for, will be required.

Lock No. 3 is located in a hill on the south side of the valley and raises the water to the summit level, which the company has assumed will be 106 feet above mean tide, giving the lock 40 feet lift. For reasons given elsewhere, the Board believes the level will be about 110 feet, in which case the lock will have a lift of 44 feet.

There is but one opening to be closed here, the saddles in the adjacent hills being above the summit level. The company proposes to close this with a concrete dam with sluice openings similar to those at Locks No. 1 and 2. The crest length of the dam will be 750 feet, and the height above the bed of the Deseado will be 63 feet. No borings have been taken at this site, and it is not known whether a suitable foundation for a concrete dam can be found.

A weir 200 feet long is to be placed in the hill on the north side of the valley, and channels excavated to and from it.

A basin about 2,000 feet long is formed immediately above Lock No. 3, affording an adequate passing place; one-fourth of a mile beyond the basin the line reaches the east end of the great cut through the east divide.

The canal cross section proposed by the company between the locks is the same as between Lock No. 1 and Greytown Harbor, viz, 120 feet bottom width. In the opinion of the Board, navigation would be better served by reducing the width to 100 feet, and providing passing places immediately above and below each lock.

It is said, in the final report on location, of January 31, 1890, that the locks are to be 650 feet long in the chamber by 70 feet wide. In later publications, it is stated by the company that the width is to be 80 feet. The Board has been informed recently, however, that this increase of width has not been determined on, and the company's estimates do not provide for it.

The dimensions should be determined by the classes of vessels which are expected to use the canal. If it is to be adapted for the passage of the largest war ships, 70 feet will not be sufficient. The U. S. S. *Iowa*, for example, has a beam of 72 feet 3 inches, and proposals are soon to be opened for others of the same beam, while it is understood that war ships of even greater beam, 75 feet, are in contemplation.

For present purposes, 70 feet wide is sufficient, but the largest vessels are proving to be the most economical freight carriers, and the dimensions of the locks should be fixed with regard to the probable increase in dimensions of vessels in the near future. A future need for large locks could be met by the construction of new ones; but in any case the cost would not be increased on account of the additional width recommended more than $1,250,000 for the entire canal.

In the opinion of the Board the width of 80 feet should be adopted, and this width is provided for in the estimates of the Board.

As before stated, the three locks from sea to summit level at 110 feet will have lifts of 31, 35, and 44 feet, respectively. There is nothing necessarily impracticable in so great a lift as 44 feet, although it is without precedent. With an increase in lift the weight of the gates at the foot of the lock chamber becomes greater, but with the machinery used for the operation of locks in modern practice, there need be no difficulty in handling them. No compelling reason can be given, however, for such an extreme lift in this locality, while several reasons of much weight suggest a more moderate one. The Board proposes to substitute a system of four locks, the one nearest the sea to have a lift of 26 feet from the level of mean tide; the remaining three, lifts of 28 feet each. This arrangement provides structures of less weight than those proposed by the company, which is important in view of the fact that they must rest on clay foundations. The weight of gates will be less, and the time required for lockage somewhat reduced. The result will be a simplification of the system, a more conservative course as regards the dimensions and weights of the structures, a slightly increased capacity for the passage of vessels, and a reduced consumption of water from the summit level on the one hand, as against a somewhat greater first cost and cost of operation on the other.

The canal company has no detailed plans of the locks and other structures for which its estimates are made, and the Board has had to prepare preliminary drawings for the lock estimates, which take into account also a complete equipment of operating machinery, such as recent experience shows necessary; the estimate of weight of gates is based on the actual weight of the gates just built for the St. Marys Falls Canal. Data as to the cost of the operating machinery are drawn from the same source.

For valuable data with reference to the construction of the new Sault Ste. Marie Lock, and for much other useful information, the Board is indebted to the late General Poe.

A system of culverts for filling and discharging the lock has been provided, and also a system of steel I beams built into the concrete floor, carrying out the idea of concrete and iron construction which has been successfully exemplified in recent arch bridges. These details, however, are used only as a means of arriving at a fairly satisfactory idea of cost.

The estimated quantities exceed those shown in the company's estimates, but are based on reliable data, and are believed to be substantially correct. It has been necessary also to increase the unit prices; for example, the price allowed by the company for concrete, $6 per cubic yard, is only about two-thirds the actual cost of concrete of similar composition used on a large scale in the locks of the Hennepin Canal where the conditions for economical work were much more favorable than in Nicaragua in every respect, except as to the cost of cement, the saving in the latter item not being sufficient to offset the increased cost due to the more adverse conditions of locality and climate. The result has been a large increase in the estimates of the cost of locks.

The borings indicate that the material to be excavated in this section will be clay. It is important, therefore, to consider its characteristics, both as regards its suitability for the foundations of structures and its probable behavior in the sides of deep cuts.

A reddish-brown clay, varying somewhat in tint, is found everywhere between Lake Nicaragua and the swamps near the coast; the steep hills and the deep ravines passed over by the Board during their inspection of the canal and embankment lines showed surprisingly little scour, although in a region of rainfall several times greater than anywhere in the United States.

Other observations confirmed these favorable indications.

Before the suspension of work on the canal the company built 11 miles of railroad from Greytown Lagoon westward, as part of the service line to Ochoa. The western portion passed through a slightly rolling district, where several cuts, some as deep as 20 feet with slopes of from ½:1 to 1:1 were made in the clay hills; the tool marks left by the workmen two or three years before still showed plainly in the sides of the cuts. Although it had been raining every day for some time, the material when examined was hard and firm, and the side ditches of the roadbed were remarkably clean. From these facts, the Board formed a favorable opinion of the material, which was strengthened by later observations in Costa Rica. The railroad from Port Limon to San José has a large number of cuts in clay, several of which are over 100 feet deep, with slopes of ½:1. During the visit of the Board to San José, a heavy rain occurred, causing a large number of land slides which stopped trains, and the Board returned to the seacoast partly by means of hand cars and partly on foot. An excellent opportunity was thus given to observe the effect of an unusually severe tropical rain on the steep clay slopes. Although the masses of clay which had fallen from the sides of the cuts were sufficient to block railway traffic, in no case were they large enough to be a serious obstruction in a canal, and a cube equal to the total amount could be removed by a dredge in a short time.

The clay appeared to be quite similar to that in Nicaragua, and when it is remembered that the slope proposed by the company for clay above water is 1½:1 instead of ½:1, as in the cuts in Costa Rica, it is believed no apprehension need be entertained of serious slides.

At the sites of Locks Nos. 1 and 2 borings have been made with an earth auger, and hard clay is reported. These reports, taken in connection with the observations of the clay in the railroad cuts, lead to the opinion that the material will form a fairly satisfactory foundation for the locks, unless local variations from general characteristics should be disclosed by fuller exploration.

EAST DIVIDE, 3.15 MILES.

This section consists of the continuous deep cut through the summit of the east divide. The general course of the valleys of the Deseado and Limpio is followed, but the streams are so crooked that the line of necessity cuts through a succession of steep hills which project into the valleys from either side. The true drainage summit is crossed near the middle of the section, 17.4 miles from Greytown Harbor, at an elevation of 322 feet above mean tide, but the deepest cutting is about one-third of a mile to the eastward, in a hill whose summit is 404 feet above mean tide, giving a cut of 324 feet. The line is entirely in curvature, with radii of from 4,520 to 7,160 feet.

The total cube of excavation in the east divide amounts to 11,700,000 cubic yards, of which 3,400,000 is clay and 8,300,000, or about 70 per cent of the total, is rock. The rock is of all degrees of hardness, from decomposed telpetate to trap. The overlying material is clay, varying in depth from nothing to 115 feet, with an average of 35 feet.

The company's estimates of rock cuts are based on a cross section having vertical sides from canal bottom to 10 feet above water, at which elevation there is a beam 5 feet in width; above this the rock is given a slope of 1 horizontal to 5 vertical; in the overlying clay the slope is 1½:1.

The company made a series of borings along the center line of the canal at intervals of about 1,000 feet, with a diamond drill, obtaining cores of the rock passed through. These cores, arranged in order, would be a valuable record, but only a few samples from a small number of borings have been preserved. These samples, with the scanty notes turned in by the chief of the boring party, and such examination of the outcrops as the Board was able to make during the inspection of the route, constitute all the information now available.

The material called "telpetate" is found in several places directly underlying the clay, and at one point the formation was 79 feet thick. It is a laminated, clayey rock, varying much in hardness, but usually soft, disintegrating more or less rapidly on exposure to the air. At one point on the bank of the Deseado it stands nearly vertical for 20 feet, and is overlaid by a hill of clay with a steep slope; in other places the indications were less favorable, the material being much disintegrated and forming natural slopes of ½:1 or flatter. The conclusion seems inevitable that flatter slopes than those assumed by the company will be required at the outset, involving an increase in the original excavation, or that a heavy maintenance expense will be incurred for some time after the completion of the work.

The most serious fact shown by the borings is the existence, at great depths below the surface, of rock more or less decomposed, which may crush when the excavation is made and cause the sounder rock above to fall. The absence of good field notes and the loss of the cores are particularly unfortunate in these cases. New borings, not only on the center lines, but on the sides of the cut, in sufficient number to disclose and define the limits of dangerous materials, are indispensable, and should be made under the constant supervision of a capable engineer.

The material reported as "talc," found in many places, is not properly so called, but, as far as can be judged from the samples, is a compact, solid rock.

In concluding the remarks on this subject, it must be added that, so far as the information goes, there are no indications of interposed clay layers or other sliding surfaces in the rock formation. There appears to be no regular stratification, and borings in the same vicinity differ greatly in character of material passed through.

The Board regrets exceedingly that it is compelled to present so inadequate a discussion of the east divide cut, the most costly section of the whole project, but the data at hand are so scanty and defective that no satisfactory treatment of the subject is possible.

EAST DIVIDE TO SAN JUAN RIVER, 12.26 MILES.

From the west end of the east divide cut the line proceeds by a tolerably direct course to a junction with the San Juan River, 1,700 feet above the mouth of the Machado, or 2,000 feet above the site of the Ochoa Dam, a total distance of 31.35 miles from Greytown Harbor.

The valley floors of the Chanchos, Nicholson, and San Francisco rivers and the Florida Lagoon where crossed by the canal are about 50 feet above mean tide, while the surface of the water is to be maintained at an elevation of 106 feet, according to the company's project, which will become 110 feet, according to the views of the Board. The valleys have considerable widths, and the Chanchos and San Francisco rivers and Florida Lagoon are crossed obliquely. These valleys are closed by a series of embankments, and the result is the formation of 6 basins of an aggregate length of 7.6 miles.

Much importance has been attached to these basins by the company as permitting a high rate of speed between the east divide and Ochoa. It is believed their value in this respect may easily be overrated; they are so short, the longest being only 2 miles and the shortest less than three-fourths of a mile, that no great increase of speed could be gained after entering one end of a basin before it would be necessary to reduce it to enter safely the narrow canal section at the other. Their principal utility, therefore, as far as the movement of vessels is concerned, is to afford passing places.

In the ridge separating the Florida Lagoon from the Machado the company has estimated for guard gates, by which communication can be closed between the basins and the San Juan in case of a break in the long line of embankments which extend eastward from Ochoa, or if for any reason it should be desired to draw down the water in the basins. There are no drawings or plans for these gates.

The canal cross section adopted for this portion of the route has a depth of 28 feet at the sides, deepening to 30 feet in the middle, the bottom width being 80 feet, and the side slopes 1½:1. There are berms of 10 feet on each side 10 feet below water surface, and again 5 feet above it. By the 2-foot deepening at the center, the bottom sloping uniformly to the sides where the original depth of 28 feet is unchanged, a nominal depth of 30 feet is obtained.

The Board inclines to the opinion that this cross section should be deepened to 30 feet for the full width, and widened from 80 to 100 feet, particularly in view of the square section and bilge keels of war ships, but has not made any addition to the estimate to provide for this increase.

THE SAN FRANCISCO EMBANKMENTS.

The great number of these embankments, large and small, the magnitude of some of them, and their important relation, individually and as a whole, to the construction and maintenance of the canal system as proposed by the company call for special consideration.

The total distance from the west side of the east divide to where the canal line reaches the San Juan at Ochoa is 12.26 miles.

In the company's reports this distance is designated the "San Francisco division," but in this report, for convenience, it is included in the general title of the eastern division.

The topography of this region is quite complicated and difficult. It may be briefly described as a succession of minor valleys intervening between the San Juan and the main ridge, which lies a few miles to the northward, and with their longer axes roughly parallel with the general southeasterly direction of both. These valleys drain into each other in a somewhat confused fashion, and in some cases the movement of water may be in either direction through the connecting links, but, broadly considered, discharge through the low crest of hills separating them from the San Juan by four principal outlets, viz, the Chanchos, Nicholson, San Francisco, and Danta rivers, the latter draining what is known as the Florida Lagoon.

This crest line, intervening between the canal line and the San Juan and somewhat vaguely defining the southern limits of the minor valleys, was developed after great labor by the surveying parties of the company.

It loops away from the canal line at the point where the latter in its westward course from the divide leaves the valley of the Limpio and falls into that of the Chanchos, and from the common point follows a succession of steep clay hills, heavily timbered, across deep swamps and flat, muddy bottoms, intersecting the valleys of the main streams and many minor depressions with a capriciously sinuous course, which lies at varying distances of one-fourth to 2½ miles from the more direct line of the canal and joins it again in the vicinity of Ochoa.

The length of the canal line between the points of junction is about 10½ miles, while that of the crest line is 15½ miles, of which 40 per cent is embankment.

The line of the so-called San Francisco embankments follows this crest line, and the purpose of the numerous dams and embankments is to dam the valleys of the rivers and close the other depressions, great and small, which are intercepted by it, and which it is necessary to build up to such height as to retain the surface level of the canal at the requisite elevation.

The effect of this is to convert the several valleys into basins, connected by narrow passages excavated to canal cross sections, as a portion of the canal route.

The total number of embankments required for this purpose, some of them of insignificant dimensions, others of great magnitude, is no less than 67, with a total crest length of about 6 miles, and with heights above the ground on which they rest varying from a few feet only to 70 feet and upward.

As stated in the final report of 1890, the canal surface elevation being fixed at 106 feet, the dams and embankments were to be raised to elevation 112 feet, giving 6 feet of free board; but by a recent modification, the excess of height is to be 8 feet instead of 6, and the 1895 estimate provides for this.

The largest of these individual embankments is the dam closing the San Francisco bottom and adjoining depressions, with a crest length of 1.2 miles, and an extreme height of 85 feet above the bed of the river. There are five others with dimensions approaching these, varying in length from 1,040 feet, with a greatest height of 60 feet, to 1,840 feet in length and height of 79 feet. These stated heights are measured from the surface of the ground, and do not include depth of foundations.

With reference to this important point, the company's borings in the beds of the Danta and Nicholson sank through 30 feet of soft mud before reaching clay, and there are two of these swamps of similar character that have not been investigated, and whose depth of mud is not known.

Assuming it to be the same, there are at least four of these larger dams that will have a total height of considerably over 100 feet above their foundations.

Referring to the practical difficulties involved in the existing climatic conditions prevailing in Nicaragua, the report of 1890 has the following judicious remark (p. 10):

> In a country subject to observed rainfalls of more than 6 inches in twenty-four hours, the problem of drainage involves dealing with forces of nature whose enormous destructive powers are a constant menace to engineering works, however careful and skillful their design and execution.

The difficulties of construction in these conditions would have been even more strikingly illustrated by citing the observed rainfalls of 9 inches in nine hours and 3 inches in a single hour.

In the Chicago paper of 1893, the chief engineer says that "the series of embankments in the San Francisco Ridge, it is frankly admitted, is the weakest feature in the whole route."

The report of 1890 states that—

> It is proposed to build all the embankments across the valleys in the disconnected portions of the ridge of "rock fills" and earth backing, the crest to be 107 feet above sea level, and with top and outer slope so shaped and paved with large stones as to admit the free flow of water over the surface without danger of injury, all other embankments to be 112 feet above sea level. All these embankments will be in fact so many waste weirs for the discharge of the surplus water at several points in the basin, with an aggregate length of 4,720 feet of spillway, and assuming that the embankments are perfectly tight, which will not be the case until several years after construction, and therefore that all the surplus water passes over the weirs, the maximum thickness of the crest will not exceed 15 inches.

It is not clear for what amount of drainage or for what area these weir arrangements were intended to provide, as the streams in question have never been gauged in flood, nor their water sheds measured.

The slopes of the rock-fill dams were to be 3:1 on the water side and 2½:1 on the dry side.

It is evident that the maintenance of these rock-fill dams, sustaining a head of 60 or more feet and with a current pouring over the crests and down the rear slope, seemed doubtful, and the company later changed its plans by dispensing with rock fill and using clay exclusively. Furthermore, the height of all the dams was raised to elevation 114, 8 feet above the canal surface. In such case the embankments are no longer to act as weirs, and the drainage is now provided for by three concrete masonry sluices, each having two openings 20 by 25 feet, placed at suitable points in hills adjacent to the main valleys of the San Francisco, Chanchos, and Danta, and built at so low a level as will provide for the diversion of these streams while the dams are under construction. In addition to the sluices are three weirs at different points; one of 250 feet, one of 200 feet, and one of 150 feet, with their crests at elevation 104, or 2 feet below the canal surface elevation 106.

The canal company has thus avoided two construction difficulties by dispensing with rock fill and the use of the dams as weirs, but has apparently repeated the error made in connection with the Ochoa Dam and the San Carlos weirs, of supposing that with an invariable width and depth of weir a uniform elevation of water surface can be maintained, with a variable afflux.

It is evident that with a fixed weir capacity, adapted to perhaps an assumed mean discharge, the water surface elevation must run down when the discharge or afflux becomes a minimum, and, on the other hand, must rise as the afflux exceeds the supposed mean.

It is also evident that, in order to meet these varying conditions of afflux and still maintain a uniform surface elevation, either the sluices must be maneuvered to regulate the discharge, or the weirs must be equipped with flash boards or movable dams that can be adjusted to meet the same purpose.

As elsewhere stated, the Board deems a surface elevation of 110 feet needful, instead of 106, as the company proposes. This will call for the raising and enlarging of all the embankments, for which the necessary additions have been made in the Board's estimate.

Using the same free board as that of the company, 8 feet, the elevation of embankment crest will be 118, and the height of crest above the average valley floor, assumed at elevation 46, will be 72 feet. The lowest valley floor is that of the Danta at elevation 40, where the mud is 30 feet deep, making the height of the dam 108 feet.

The construction of these vast accumulations of clay, under the heavy rainfall, and their effective consolidation into impermeable and stable structures will call for the exercise of the utmost care and skill. The use of animals or vehicles of any kind on the fill will in all likelihood be impracticable, and the deposit of the material and its consolidation in layers will probably involve the use of cables for delivering the clay in skips and hauling the rollers from side to side. As the San Francisco embankment alone has a total length of nearly 1¼ miles, the problem of its construction constitutes by itself a sufficiently formidable task.

The clay to be obtained from the west side of the divide cut and from excavations in the San Francisco basin is not sufficient for the construction of these embankments, which aggregate over 7,000,000 cubic yards, and a large quantity, computed at about 2,500,000 cubic yards, must either be borrowed from hills in the vicinity of the work or hauled from beyond the summit of the east divide.

For the protection of these high banks after construction the surplus rock from the divide cut may be used to cover the slopes.

The excavations of the deep mud bottoms referred to is also a difficulty. Their widths are not known, and they probably follow the line of the valleys above and below the embankment line for long distances. In order to excavate a foundation for a dam the inflow of soft mud from the two ends must be cut off, and probably the construction of crib piers, filled with stone and sunk in the mud parallel with and at suitable distances from the upper and lower foot slopes of the dam, will be the cheapest and most effective means of doing this. The cost of auxiliary work of this kind is included in the unit price ($1.50 per cubic yard) adopted by the Board for the mud excavation.

It is proper to note the multiplied points at which the canal would be exposed to injury after construction, and the comparative facility with which a breach could be made at any point on the long line of embankments, if, for any reason, military or malicious, it should be intended to destroy the canal navigation until the breach could be closed.

RAILROAD AND TELEGRAPH LINES.

The company proposes to build a single-track railroad from Greytown to Ochoa for the transportation of plant and supplies and for conveying excavated materials to points where needed or to suitable dumping grounds. The clay from the east divide will all be needed in the embankments between the east divide and Ochoa. Of the rock, about 700,000 cubic yards, solid measurement, will be required for Greytown Harbor; 100,000 cubic yards for pitching canal banks between Greytown and Lock No. 1; 250,000 cubic yards for concrete in the locks, and 2,000,000 cubic yards or more for the Ochoa Dam. For this large traffic the estimates of the company provide a single-track railroad, without sidings, terminals, or other necessary adjuncts. A line has been located, with grades running up to 3 per cent and with free use of 15-degree curves, these extreme limits being due to the difficult nature of the country.

The Board does not believe that any single-track road, and especially such a one as has been described, located in a country where the rainfall is so great and track maintenance will be so difficult, is sufficient for the business west of the east end of the divide cut, and has therefore increased the estimate to provide for a double-track railroad in this section, with stations, water tanks, machine shops, sidings, and terminals for the whole line. The estimate is necessarily approximate only for what is believed to be sufficient.

From the east end of the divide cut to Greytown Harbor it is believed that a single track will suffice with proper sidings and terminals.

The telegraph line is required, not only for the operation of the railroad, but to maintain communication between the different sections of the canal. The company's estimates are believed to be adequate.

LAKE AND RIVER DIVISION FROM OCHOA TO WEST SIDE OF LAKE NICARAGUA.

THE OCHOA DAM AND THE SAN CARLOS RIDGE.

The dam across the San Juan River at Ochoa, about 69 miles from the lake, is the main prop of the company's project, and, like the pier of a cantilever bridge, upholds the burden of the great constructions that stretch in both directions to constitute the waterway.

The bold project of extending the summit level of the canal from the lake to Ochoa, and thence to beyond the east divide within sight of the Caribbean, depends upon the successful building and maintenance of the structure.

The dam is designed—

First. To intercept the flow of the San Juan below its junction with the San Carlos and submerge the valleys of both rivers, converting them into arms of the lake. The effect of this would be to add some 2,300 square miles to the lake watershed.

Second. To maintain the water surface of the flooded valleys at such an elevation as will prevent the lake from falling below its adopted minimum stage, viz, 110 feet above sea level.

Third. To prolong the summit level eastward from the dam through the San Francisco basins and the east divide cut to Lock 3 in the Deseado Valley, 17 miles from Greytown.

Fourth. To act as a weir for a discharge over its crest of the surplus waters of the lake and San Juan watersheds.

The San Carlos is the principal affluent of the San Juan and drains an area of some 1,250 square miles, which reaches back to the lofty summits of the Costa Rican ranges, and is subject to a heavy and variable rainfall. The river therefore has a quick watershed, and is liable to heavy floods. It discharges into the San Juan about 65½ miles from the lake and 3½ miles above the proposed site of the Ochoa Dam.

The ridge that bounds the San Carlos Valley on the east side is too low at numerous points within 10 or 12 miles from the San Juan to sustain the high-water level, and 21 embankments are needed to close the gaps and raise the crest to the requisite height. At suitable points in this ridge the company proposes to build three weirs, with an aggregate length of 1,200 feet, to aid in discharging the surplus volume of the two streams, and has recently added two sluices 20 feet wide and 25 feet high for the same purpose. The San Carlos Ridge is therefore a necessary adjunct, and practically a continuation of the main work.

Since the Ochoa Dam is to sustain the volume of a reservoir nearly 3,000 square miles in area and control the entire summit level, it will determine the elevations, magnitude, and cost of all the constructions through both the east and west divides, the great embankments in the San Francisco basins, and the extensive rock and other dredging in the San Juan and lake channels, representing about one-half of the total cost of the project.

The determination of its height and other dimensions, and the selection of the materials and methods of its construction, are therefore matters of vital importance; a reduction of even a foot or two would impair navigation, and any considerable excess would endanger some of the works, while the failure of the dam would leave the navigation stranded, wreck the valley below, and possibly wash Greytown into the sea.

A work of this kind, designed to control a large river, and upon which interests of such magnitude depend, can not be too thoroughly considered or too securely built.

The engineer should know the conditions under which he is to work, the forces with which he has to contend, and the probable magnitude of their opposing action, if he is to plan his work wisely and insure its safety. It is important to know—

First. What is the nature of the river bed and banks upon and between which the dam is to be built.

Second. What are the physics of the stream itself; its range between low and high water stages; its varying slopes, velocity, and volume; the magnitude, duration, and frequency of its floods.

Unfortunately, information of this kind is seriously deficient.

The company's surveys are mainly devoted to topography, and did not include the collection of hydraulic data. No survey was made of the river, and but one gauging, and that of no present value, as the stage of river when it was made is not known. For information of this kind, recourse must be had to the imperfect data given in the Childs and Lull reports of 1852 and 1873, respectively, and obtained during the recent inspection of the river by the Board.

The company has no detailed plans or specifications for the dam, and the following account of the proposed method of construction is quoted from the Final Location Report of 1890:

> The section of the river from Ochoa to the lake is to be made navigable by the construction of a dam at Ochoa, just below the Machado, maintaining the water at the summit level of 106 feet above sea level. It may here be explained that this elevation hitherto treated as the summit level is 4 feet below the lake, a fall of three-quarters of an inch to the mile being allowed for the slope necessary to discharge its waters, although for all purposes of navigation that portion of the river is converted into an extension of the lake.
>
> The dam is located between two steep hills, and its length of weir on the crest will be 1,250 feet, and abutments 650 feet. The average depth of the water in the river was at the time of the survey 8 feet, and the maximum depth close to the southern abutment 14 feet, the width between banks being 950 feet. With a mean flow in the river of 20,000 cubic feet per second, the thickness of water on top of the weir will be about 3½ feet.

The dam is proposed to be built of rock fill and earth backing, in all respects similar to all the other large embankments and weirs already described. Its average height above the river bottom is 61 feet, its thickness at the top 25 feet, and at the bottom 500 feet. The core of the rock portion will be made of smaller stones, gravel, and refuse from the rock cuts, with three rows of sheet piling from abutment to abutment, and substantial concrete core walls from the ends of the sheet piling carried well into the abutment hills and up along the slope beyond the maximum flood level. The upper portion and long flat apron will be composed of stones of the largest dimensions that can be properly handled and arranged, the interstices being filled from behind with small stones, gravel, and earth dumped from suitable trestles.

The following from a paper prepared by the chief engineer of the company for the Water Commerce Congress at Chicago in 1893, pages 28 et seq., gives a fuller description:

The Ochoa and Tola dams are the keys controlling this great problem at the east and west ends of the summit level, and should not be passed without special notice, particularly so the former, in which a novel method of construction is contemplated. This work has been for years the subject of long study and careful consideration. The diversion of the River San Juan is well-nigh impossible, and construction by the usual methods, with either cut stone or concrete, of so important a work in opposition to the mighty power of the stream is a problem involving the most serious difficulties. It was at first proposed to build a stone dam upon a series of arches supported by piers starting from the foundation, through which the river waters could flow freely during the construction of the main part of the structure, these openings to be closed by gates in the upper side when the upper part of the dam, its approaches and aprons, were completed; and then to be filled with masonry from the lower side, while the water was rising in the basin. This was, perhaps, as a practical solution, probably the best under the circumstances, for that style of dam; but its execution would be tedious, difficult, and expensive, and there was to be always present an element of doubt not easy to eliminate as to the final success. The building of the foundations and pilasters for the support of the arches in constant contention with the whole river would be a most difficult undertaking, in which the items of time and cost would remain unknown quantities to its completion. Another idea has since been suggested, which seems to embody simplicity, economy, and safety. It consists in dumping from an aerial suspension conveyor large and small material properly assorted, across the river from bank to bank until a barrier is created sufficiently high and strong to arrest the flow and hold the waters at the required level, the body of the dam to be made up of large blocks of stone, weighing from 1 to 10 tons, and smaller material to fill the voids. Its base will be quite broad as compared with the height, probably from 400 to 500 feet between the foot of the upstream slope and the end of the apron. The top is estimated 30 feet wide, the rock upstream slope 1 to 1, and the apron, or downstream slope, 4 to 1, with the lower portion flattening down to 5 or 6 to 1. On the upstream side small material, such as stone, fragments of gravel, clay, etc., selected as circumstances may require, will be deposited as the work advances, in sufficient quantity, as tight as wanted. It is not expected or even desirable to have a water-tight structure, the object sought being simply to oppose such an obstruction to the river as may be necessary to hold the waters at the required level. The minimum flow of the river is about ten times the water needed for working the canal. Consequently, nine-tenths of it can be wasted with advantage. That the dam will eventually become tight there can be no doubt, as the small drifts and detritus forced in by the current will gradually fill the voids and consolidate the structure.

The method of construction will be quite simple. After protecting the abutments against possible erosion, large pieces of rock will be dumped in the bed of the stream from three or four cableways spanning the valley. The material should be distributed uniformly over the area under the main portion of the dam, commencing upstream and keeping up, as nearly as possible, an even level. Scouring will soon cause settling of the blocks into firmer soil, the upper level in the meantime being constantly raised by depositing more stone, while the small material is being forced by the current into the voids, and the overflow dislodging and rearranging the unstable blocks until they reach a final resting place. This process to be continued until the resistance at the bottom becomes so great as to check scouring due to maximum pressure, when the dam will be carried up to the desired level. The river, in the meantime running over the mound, will readjust the material in and adapt the apron to the necessary conditions of stability to withstand the effect of the fall, and carry off the water safely. If the dam is then raised so as to shut off a whole or the largest part of the river flow, which can by that time be discharged over the waste weirs, the structure will be permanent. If the river is not able to prevent the completion of this work, having, on the contrary, greatly contributed to its construction by a better distribution and consolidation of the material, now that the waters are diverted to another outlet, no fear need be entertained as to injury from that source. There may be some settlement and final readjustment of the component parts for some time after completion, but that can be easily remedied by depositing more material where needed. It is believed that this dam will be safer, as it is by far more economical, than a stone dam. An earthquake might cause serious damage to a masonry dam, but it can do no harm to this. On the contrary it may add to its consolidation by bringing the parts in closer contact. There are no cemented joints to be opened, and a seismic disturbance would have a tendency to compact rather than to disintegrate the large mass. The rock for the dam will be brought by rail from the divide, and delivered immediately under the wire cables, each one of which will be capable of handling and depositing about 1,000 tons in ten hours. Consequently the work can be completed in from four to five years, and, if it need be, in less time.

On page 27 of the same paper it is stated that—

At the site of the Ochoa Dam, gravel, clay, and rock, in the order named, are shown by the borings.

On pages 20 and 21 it is stated that the weir on the crest of the dam is to have a length of 1,250 feet, with its sill at elevation 105, 1 foot below the water surface, while the San Carlos Ridge weirs, with a length of 1,200 feet, have their sills at elevation 103.5, 2½ feet below water surface.

The company assumes, therefore, that there will be at all times streams of at least these depths flowing over the weirs, and computes the corresponding discharge at 14,200 cubic feet per second, with the water surface at normal level, viz, elevation 106.

The cubic contents of the dam, as above described, is given in the company's estimates of 1890 as 880,000 cubic yards; but this has recently been increased 50 per cent, and appears in the estimates of August, 1895, as 1,200,000 cubic yards.

It is not known upon what basis the company assumes that the slope of the river from the lake to the dam will be 4 feet when the water surface at the dam is at an elevation of 106 feet.

So far as the Board can determine, the slope at low stage of river and lake will be 0; in other words, that, to prevent the lake from falling below summit level elevation 110, during the dry season, the water surface at Ochoa must be held at the same or a greater elevation, the height of the dam be correspondingly increased, and all sources of waste be stopped. Furthermore, the company assumes (p. 19, Chicago paper) a possible maximum discharge from the watershed, with both rivers in full flood, of 63,000 cubic feet per second. No gaugings have ever been made at high stages, and reliable data are lacking; but from such sources of information as were accessible to and from observations made by the Board, and by various methods of computation, it is clear that high floods, discharging as much as 125,000, and possibly 150,000, cubic feet per second, are to be expected at intervals of a few years, and that the dam is likely to be subjected to such floods during construction and subsequently.

The problem at Ochoa, therefore, is to build a dam in opposition to the tremendous and unknown forces of the river floods, while the imperative requirements of the completed structure are that it shall be permanent beyond peradventure and practically impermeable. In a structure so important as this, where failure would mean destruction to property and population from the dam to the sea, and suspension for several years of navigation through the canal, only the most secure and stable structure should be considered. It is not a place to practice small economies.

The conditions would be fully met by a masonry dam on a solid rock foundation, if such could be found.

No such site is at present known nearer than Machuca Rapids, 17 miles above, and no search has been made for any. The company's location was fixed with reference to topographical considerations, and the geological investigation was both scanty and unsatisfactory. In January and February, 1888, borings were made in the bed and banks of the river to ascertain the nature and disposition of the subjacent materials. The party was provided merely with earth augers for boring into clay, and with pipes and sand pumps for exploring the sandy bed, but had no drills for penetrating and testing rock, in order, if found, to ascertain its character and quantity.

The following table gives in a condensed form the information obtained:

Record of borings with earth auger and pipe and sand pump at site of Ochoa Dam.

Location of boring.	Designation of boring.	Depth of boring below surface of ground.	Depth of boring below surface of water in river.	Material passed through.	Material reported at bottom of boring.	Distance above (+) and below (−) sea level.	Remarks of engineer in charge of boring.
		Feet.	*Feet.*			*Feet.*	
On north bank, 120 feet from river, on center line of dam.	A	30	......	Clay	Rock	+76	Rock, thought to be a bowlder.
On north bank, 90 feet from river, 250 feet above center line of dam.	B	35	......	.....do	.....do	+26.7	
On north bank, 110 feet from river, 120 feet above center line of dam.	C	44	......	.....do	.....do	+19.6	
On north bank, near water's edge, 100 feet above center line of dam.	D	58	......	.....do	.....do	— 1.4	10 feet above rock, clay and sand. Rock appeared very hard.
On south bank, 30 feet from river, 330 feet below center line of dam.	E	42	......	.....do	.....do	+25	Rock, thought to be a bowlder
On south bank, near water's edge, 120 feet below center line of dam.	F	25	......	.....do	Bowlder ..	+34	
On south bank, near water's edge, on center line of dam.	G	10	......	.....do	.....do	+38.7	
On south bank, 160 feet from river, on center line of dam.	H	22	......	10 feet clay, then 12 feet sand and gravel.	.....do	+77	
On south bank, 150 feet from river, 70 feet below center line of dam.	I	15	......	Clay	.....do	+92	
On south bank, 180 feet from river, 60 feet below center line of dam.	J	54	......	.....do	Clay	+52	
On south bank, 60 feet from river, on center line of dam.	K	37	......	9 feet clay, then 24 feet clay and sand.	.....do	+21	
In river, 200 feet from south bank.	L	20	35	Sand	Sand	+13.3	These borings at nearly the same point.
Do	M	24	36	.....do	.....do	+12.3	
Middle of river....................	N	21	30	.....do	.....do	+18.3	
In river, 200 feet from north bank.	O	18	24	.....do	.....do	+24.3	
In river, 10 feet from north bank.	P	39	44	Clay	Rock	+ 4.3	Struck solid rock; very hard.
South bank, on water's edge...	Q	39	......	.....do	Clay hard-pan.	+ 9.3	

NOTE.—Surface elevation of river February 5-16, 1888, 48.3, which is a rather low stage. Borings L to Q, inclusive, were taken during this period.

The borings show that the hills forming the river banks are of clay which is fairly compact. One of these borings, however, shows a considerable depth of sand and gravel underlying clay at a distance of 160 feet from the bank of the river, and points out a possible source of danger to the abutments. Five borings only, viz, L, M, N, O, and P, were taken in midstream. In four of these nothing but sand is reported to a depth of 24 feet. It is explained that these borings were not carried to greater depths, because the pipes became clogged with gravel, which could not be removed with sand pumps, and for the removal of which no other provision had been made.

"Rock" is reported in several borings at depths differing greatly even within short distances, and it is doubtful if rock was found in a single instance, when it is taken into account that the only tool for determining the character of the material was a common auger.

The boring marked D, taken near the water's edge on the north bank of the river, reached a depth of nearly 14 feet below the deepest boring in the river bed. This renders it very probable that at least that depth of sand or gravel overlies any harder material, if any, in the center of the stream, and this probability is strengthened by the fact that in the San Juan above the San Carlos the depth of water is as great in some places as 50 or 60 feet, reaching much below sea level.

Nevertheless, an exhaustive search should be made for a suitable site for a masonry dam before accepting one of inferior character. If the route adopted by the company from Ochoa to the sea, through the San Francisco basins to the valley of the Deseado, with some of the undeniable advantages that it would possess is to be retained, the limits for a possible location of the Ochoa Dam are quite narrow. Above the mouth of the San Carlos the deep channel would make it difficult to build masonry foundations, and the canal extension to reach it would be costly. Below Ochoa reconnoissances in the vicinity of the mouth of the Serapiqui and for a few miles above that point have made it almost certain that no site for a high dam exists in that vicinity. The examination would therefore be confined to a stretch of river extending not more than 10 or 12 miles above Ochoa and not more than 8 or 10 below it. The Board, however, while insisting upon the necessity for this investigation, can not prejudge its outcome, and must, in accordance with its instructions, report upon the plan proposed by the company.

The structure proposed by the company, as previously described, is a rock fill of not excessive dimensions, to be composed of loose masses of rock of assorted sizes, dropped into the river and permitted to reach positions of stability under the action of the river, and in conflict with its floods. It is assumed that the resultant slope upstream will be 1:1, and the downstream slope 6:1 near the base to 4 or 2:1 at the top.

The weir crest of the dam is to be at elevation 105, about 60 feet above the low river, and the base supposed to be about 25 feet below it, giving a total height to the structure of 85 feet.

Smaller materials, stone, gravel, and clay, etc., are to be deposited against the upstream face as the work advances, and, working into the rock fill, gradually tighten it, with an ultimate upstream slope of 3:1.

The shore connections are to be made by means of lines of sheet piling, the soil to be excavated between them, and core walls built of concrete.

The company considers that it will not be needful to make this dam entirely water-tight, as the large surplus discharge of the river will permit considerable leakage without interference with canal requirements. This assumption, however, is quite erroneous.

The Board has given careful and laborious consideration to the problem of this dam as the most difficult and important individual work in the project, and has sought every means available to investigate the chances of its successful construction.

The dam, if finished, could not be overturned or pushed from its base; but questions arise as to the strength of its foundations, as to its resistance to floods during construction, as to making it tight enough to retain in the dry season a sufficient amount of water for canal uses, and as to the practicability of using the completed dam as a weir.

It may be said at once that the structure as proposed, of loose rubble, built in a sand foundation of unknown depth, in conflict with a powerful stream subject to floods, and to be used as a weir after completion for the discharge of the river, has no precedent in any engineering construction.

The idea of the "rock fill" was doubtless suggested by the works of that kind that have been built in the West, and it will be useful to give the particulars in reference to some of these, and, from their success or failure and the precautions found necessary in building them or the defects which led to their destruction, to extract such lessons as may be applicable to the case in question.

Dams of rock fill, with various modifications, have been in use for several years and have found their principal development in the mining and arid regions of the United States. Several have been built by hydraulic mining companies in California. The California dams usually contain more or less crib work which is exposed to decay, but the dams are intended to serve only a temporary purpose. The foundation is usually of rock. The slopes are 1:1 or steeper, the face being heavy rubble, of the largest stone obtainable from the quarry, and laid with derricks. The smaller stones and refuse are used for the interior filling, which is dumped in. The upstream face is provided with a water-tight covering of 3-inch plank, of one, two, and three thicknesses from the top downward to the bottom, secured to the crib work or to timbers anchored into the body of the dam, carefully calked, and fitted at the lower edge to the foundation. Several of these structures will be described.

THE ENGLISH DAM.

The English Dam on the Yuba River in California was built in 1856–1858 as a crib dam. It was 110 feet wide at the foundation, which was on hard trap or shale. The total height above the foundation was about 89 feet at the center of the dam. Its width at the base was 100 feet. In 1876–77 it was decided to raise the crest of the dam. The timber in the outer face of the crib work was renewed wherever decayed; a mass of rocks was deposited against the downstream slope, the face being heavy dry rubble, laid carefully, and the space between this and the crib filled with loose rock. The downstream face had a slope of nearly 1:1. The upper 7 feet was made wholly of substantial timber work, connected with the water-tight plank facing of the original crib work. The crest of the completed dam was 131 feet above the deepest part of the foundation. From 1858 to 1883 the water in the reservoir was raised every year to the high-water mark, which, in the new structure, was 14 inches below the crest of the new timber work. No sign of weakness was ever observed.

At 5.30 a. m. of June 18, 1883, a watchman, in making his usual rounds, heard two sharp explosions, and hastened to a point from which he had a view of the dam. The water was pouring through an opening in the upper timber work over the crest of the stonework; in a few moments the crest of the dam for a length of 175 feet was swept away, and an immense opening was cut in the foundation. In the space of one hour fully 600,000,000 cubic feet of water were discharged into the canyon below at the rate of 166,000 cubic feet per second.

The failure is supposed to have been due to the decay of the timber in the crib work, causing a settlement in the rock fill and permitting a sheet of water of considerable depth to pass over it.

THE BOWMAN DAM.

The Bowman Dam was built a short distance below the English Dam, in the same valley. When first built it was a crib dam, 72 feet high, filled with rock. In 1875–76 it was raised to its full height, 100 feet, by a rock fill against the downstream side of the crib and above its crest. The completed dam is 425 feet long on the crest, with slopes of 1:1, or a little steeper, on both sides. It was faced with heavy rubble, laid with derricks. On the downstream face the rubble was 15 feet thick at the base and 6 to 8 feet thick at the top. The upstream face was covered with plank sheathing, calked and made water-tight. The top of the dam was covered with coping of plank anchored into the stonework. At the time of the failure of the English Dam the entire flood passed over the Bowman Dam without injuring it.

Other dams of the same general character still doing service might be cited, but they differ in no important particular from the English and Bowman dams. The essential features were an impermeable foundation, and a crib core, with a water-tight plank sheathing. In a few other localities dams have been built without the plank sheathing, and in some respects more nearly comparable with the dam proposed at Ochoa.

WALNUT GROVE DAM, ARIZONA.

This dam was built in 1888. It was 420 feet long on the crest, 110 feet in height, 138 feet wide at the base, and 15 feet wide at the top. Both sides were faced with dry rubble walls 20 feet thick at the base and 5 feet thick at the top. The upstream face was covered with a water-tight plank sheathing. A mass of loose rock, having a slope of 1:1, was piled against the downstream side for half its height. The foundation was rock.

During a great flood in February, 1890, the water poured over the crest to a depth of 3 feet for six hours, when the dam gave way and was entirely destroyed.

CASTLEWOOD DAM, COLORADO.

This is a loose rock dam, with masonry face, and is 586 feet long on the crest, 63½ feet high, 85 feet wide at the base, and 8 feet wide at the top. The underlying material is a compact bed of clay and hardpan, which was excavated 15 feet deep over the site of the dam. The upstream slope is 1:10; the downstream slope 1:1. Both face walls have a thickness of 5 feet, and are laid in cement mortar; the interior filling was laid dry, but each stone was carefully placed. When first built, the crest for a distance of 100 feet was left 4 feet lower than the remainder of the dam to form a waste weir, but this has been filled up, and a sluiceway excavated through a rock in a hill forming one of the abutments. The dam is still in good order.

THE PECOS DAM, NEW MEXICO.

This dam was built in 1890. It had a crest length of 1,040 feet, with a height of 45 feet above the lowest point in the foundation. It was built of loose rock, of gypsum and limestone, which was of poor quality, and broken into small pieces in excavating. The upstream slope appears to have been about ½:1, and was faced with a hand-laid wall. The downstream slope was 1:1 without facing. An earth embankment was built against the upstream side, with an upstream slope of 2:1. It was put in dry, and, when the first flood came against it, slid away, and the water poured through the rock fill without doing it any injury. After the flood subsided the embankment was rebuilt in a more thorough manner, with an upstream slope of 3:1. In 1893 there occurred a very high flood, and, the spillway being insufficient, the water poured over the top of the dam to a depth of 5 inches, which was sufficient to cause its speedy destruction.

ST. CHRISTOPHER DAM, FRANCE.

The following description of this very interesting example of a rock-fill dam is taken from the Engineering News of January 8, 1887, which is credited by that paper to the proceedings of the Institution of Civil Engineers:

> This was originally a bank of rough stone 65 feet high for carrying the canal (Marseilles Canal) across the valley, and constructed with very little care, without any intention of using it as a reservoir dam. When it was determined to adapt it to this purpose the water-tight lining of the canal was removed and the turbid water allowed to sink into the dry stone work. This produced considerable settlement, but at the same time filled up the cavities with deposit. Water was then gradually let into the reservoir. At first large quantities made their way through the dam, but the amount of leakage diminished by degrees and the inner face of the dam was then covered with good masonry, 10 feet thick at the bottom and 1½ feet at the top. This was expected to render it water-tight, but did not have this effect, and upon readmitting the water large fissures appeared on the face, particularly near the bottom. Several rows of piles were then driven near the foot and the cracks filled up, and the bank is now practically water-tight.

THE CASCADE FILL.

The Cascade Fill, on the line of the Erie Railroad, has been referred to in connection with the proposed Ochoa Dam, and illustrates so well some of the features of rock fills that a description is proper in this connection.

The track of the Erie Railroad crosses the valley of Cascade Creek, 175 feet above the bottom of the gorge. It was originally carried on a timber arch which was replaced about 1860 by an embankment. In order to avoid the use of a culvert through the embankment the lower portion was made of clean riprap, which formed a drain for the creek. The upper portion was made of smaller stone, and with anticipation that the rainfall might not pass the largest floods a tunnel was driven around one end of the fill through the rock of the hill, as a discharge culvert.

In 1875 the tunnel discharged a large amount of water for the first time. As late as 1888 the rock fill continued to pass the ordinary drainage and even moderate floods, but since that time it has become practically water-tight and the discharge is through the tunnel.

The rock-fill dams which have been cited differ from the proposed Ochoa Dam in many respects, and the limits within which they may be regarded as precedents must be kept clearly in mind. In no case has the rock fill been relied upon to make a water-tight dam. A plank sheathing or a skin of masonry laid in cement, or a carefully built embankment has been adopted as an absolutely necessary feature. In the case of the Cascade Fill, the riprap was intended to act as a substitute for a culvert, and answered its purpose sufficiently for many years except for very heavy rains.

In nearly all cases the foundation is rock, but there are two notable exceptions. The first is the Castlewood Dam, in Colorado, where the foundation is a compact bed of clay and hard pan. The second is the St. Christopher, where much settlement and leakage resulted, which was finally stopped by sheet piling.

The English, Walnut Grove, and Pecos dams failed immediately or within a few hours when the water passed over their crests, and they became weirs. The failure of the English Dam was caused, probably, by a settlement of the stone breaking the connection between the new timberwork on the summit of the dam and the older crib work below and permitting the new work to be swept away; but whatever the cause may have been, it is an important fact that as soon as a sheet of water 6 feet or more in depth commenced to pass over the unprotected crest of the rock-fill dam its destruction followed in a few moments. The resistance of the Bowman Dam, over which the vast liberated flood passed so quickly, was probably due to the protection of the crest by timberwork, which prevented the formation of a breach in the rock fill, and it may be presumed that the downstream face of the dam had been laid with care, but it must be remembered that the trial lasted only about an hour.

There has been much dispute as to the care with which the Walnut Grove Dam was built; the slopes were considerably steeper than 1:1, and although the walls on both sides were hand laid, the dam failed within six hours after having been overtopped with 3 feet of water.

The failure of the Pecos Dam is not so surprising, for the material of which it was composed appears to have been already so finely broken that it could offer little resistance to a strong current, and its speedy failure when overtopped was inevitable.

No case is known of an existing rock-fill dam where its use as a weir is intended, and the failures above cited point out the danger, which there would be no justification for incurring, for the completed structure at Ochoa, where the interests involved will be so vast.

It is inevitable, however, that during the construction of the Ochoa Dam the flood waters will pass over it, and the question of their probable effect is of great importance.

The conditions at Ochoa will be in some respects more favorable, in some respects less favorable, than in the cases above mentioned; the material to be used will be in large masses, and the downstream slope will be flatter. On the other hand, the annual floods of the San Juan will be discharged over the mound for several years during its construction. If a flood like that of 1888 occurs during this period, the depth of the sheet of water passing over the dam will be 10 feet or more in thickness, and will exert an enormous force to displace the stones on the crest of the downstream slope, a force which they will be the less able to resist because in the earlier stages of the work it will be impossible to arrange them with any regularity so as to form a dry wall or paved surface.

The great weirs known as "anicuts" built across the wide, flat, sandy, river beds of India are instructive in this connection. While these weirs are only 10 to 20 feet in height above the bed of the river, immense floods pass over them, sometimes for a depth of 20 feet. The weirs are built during the season of low water, when the flow of the river is small and can be diverted, and any repairs that may be necessary can be made during the long dry season that presently follows the brief rainy season. The river bed for a distance of 150 feet or more below the weir is protected by a heavy layer of riprap, covered by a paving of large stones laid by hand as close as possible, with their longest dimension vertical. A system of concrete or rubble walls whose foundations generally penetrate several feet into the river bed divides this protecting apron into areas of 20 to 30 feet square, so as to confine the limits of injury which any portion may receive. The slope of the apron is never steeper than 10 horizontal to 1 vertical, and more often 20:1.

During the construction of the Ochoa Dam the river can not be diverted either wholly or in part until the dam has been built to a considerable height above the present river bed, and the top and downstream slope of the dam, corresponding at this stage with the apron of a weir in India, can not be protected by a regularly laid surface. The stones, however, may be very much larger, and thus compensate somewhat for irregularity of arrangement.

Several of the larger Indian weirs resemble the Ochoa Dam in that they are built on sand extending far below the foundations, but they are never of great height, and the penetration of the masonry of the weir below the river bed is usually greater than the elevation of the crest above the river bed. It would be impracticable to realize a like condition at Ochoa.

It appears from this account of typical existing dams that, although rock-fill dams are not new, and although weirs have been built on sand and maintained successfully, the Ochoa Dam is actually without precedent in its more serious aspects, and its construction will be far more difficult than any that have been mentioned. The successful rock-fill dams have impervious foundations, and are made water-tight by sheathing or masonry. The materials in them are in great part hand laid adding greatly to their stability, and none of them has been built in conflict with the forces of a great river or was intended to be used as a weir for the discharge of floods.

As to this last point, the Board is clear in its judgment that no such endeavor should be made in the case of the Ochoa Dam, as involving an unwarrantable hazard to the safety of the structure and of the canal navigation.

It will be seen that the construction of a loose rubble dam without masonry and lacking bond and coherence, resting in a bed of sand of unknown depth, intended to endure the constant flow of water over its crest and down its rear slopes, and to resist the passage of floods of many feet depth, depending for its maintenance solely upon the stability that the individual stones exposed to the impact and power of the stream may be able to derive from their weight and contact with the adjacent pieces of rubble, has little resemblance to the low and carefully hand-packed anicuts built during the dry season, or to rock fills of the mining regions, built dry on rock, with crib work whose defect is its perishability, and which are not intended to bear an overflow.

In the case of the Ochoa Dam, while there are no precedents of similar design that can usefully be studied as a guide, there are many failures of dams of various types that may wisely be considered as warnings when the subtle and often incalculable power of a large body of water under high pressure and in full movement is in question.

Although evidently invested with special and unusual difficulties, it can not, therefore, be inferred that the construction of a dam at Ochoa is to be regarded as impracticable or beyond the resources of modern engineering. Engineers are loath to admit that anything not forbidden by the known laws of nature is impossible, provided the need of doing it and the means of paying for it are commensurate with the magnitude of the undertaking; but no one will deny that the formidable nature of the task and the seriousness of the interests depending upon its successful execution make greater the urgency that every detail and particular affecting the problem shall be closely studied and accurately determined, without doubt or uncertainty, as far as the methods and appliances of modern science shall avail to ascertain them, in order that the plans of construction may be intelligently formulated, the necessary appliances be considered to meet contingencies, the risk and difficulties of construction and maintenance be reduced to a minimum, and a fairly adequate estimate be made of the cost of the completed work, and of the time required to build it. There are chances and hazards in all great undertakings, and the history, both technical and financial, of engineering constructions, especially those dealing with hydraulic problems, but emphasizes the necessity of thorough exploration, and full and precise ascertainment of essential facts before proceeding with the actual execution and expenditure for construction.

The Board has endeavored, notwithstanding the lack of proper data, to formulate some views as to what might seem to be the safest method of constructing the dam, and as to the dimensions it should have.

One view contemplates the building of the dam subject to the floods of the river until it should be raised to such an altitude as to admit of completing the upper part rapidly in one low-water season.

The second considers the advantage of constructing sluices in the San Carlos Ridge of such dimensions as should give relief in part or altogether, with the idea, subsequent to the completion of the dam, of continuing the sluices in service as a means of regulating the water discharge, and the maintenance within proper or possible limits of the summit level elevation.

In view of the probability that the work may be subjected to a flood so great as 150,000 cubic feet per second, the Board considers that this contingency should be regarded as a datum for safety in arranging the details of construction.

Another datum regulates the height. The maintenance of the lake level at a minimum of 110 will probably involve the necessity of holding it at times at 112 or even more. The Ochoa Dam must meet this contingency, and its crest elevation, allowing for possible subsidence and a proper free board, should be 120.

The weakest point of a dam built as the company proposes would probably be at the river bank, where the loose rock will meet the steep clay slope. The method proposed for protecting this point by lines of sheet piling and concrete core seems entirely inadequate. A better construction would involve the use of a caisson on each side of the river, located so as to be partly in the river channel and partly in the firm clay bank, and sunk by the pneumatic process to bed rock if within reach by that means, or if not, at least below reach of scour. It seems probable that either bed rock or a mass of bowlders would be found near sea level, elevation O. The caisson should be surmounted by a concrete wall, extending up the hillside beyond the caisson to the highest elevation to be reached by the water surface after the completion of the dam, say 114 or 116. A trench 20 feet or so in depth, or deeper if necessary to reach firm material, should be excavated in the hillside for the core wall. This work done, the river banks and hillsides below high-water level should be covered with a heavy mass of large stones and an additional amount held in reserve before depositing any rock in the river. The result of this would be to contract somewhat the width of the river channel, which would at once scour out so as to maintain its normal cross section. A considerable scour would be desirable, because it is important that the rock mass be sunk deeply into the river bed, since, if rock or a bed of bowlders or heavy gravel can be reached, the safety of the structure will be increased greatly. In depositing rock in the river those methods should be used which will induce scour, and possibly the building out from each side may best answer this purpose.

The proposition of the company to build the main portion of the dam with stones of large size, with only enough small pieces to fill voids, is sound, and precautions should be taken to have the surface of the mound covered with the heaviest rock obtainable prior to every flood season. If the work is carried up over the whole width of the stream, a regular cross section should be maintained, so that the force of the flood will not be concentrated at any one point. The downstream slope should be made very flat—10:1 will be none too flat, and will give trouble enough in maintaining it. As the work rises the danger of injury by floods will increase. Should sand under the mound scour out at any point a settlement would occur, a channel would be formed through the mound, and the destructive power of the current be greatly increased. If, however, the mound can be successfully raised to an elevation of 70 feet above sea level, or 35 feet above the present bed of the river, it will be then possible to build the remainder of the dam to full height in a single low-water season, the reduced flow of the river spouting through the interstices of the dam, by using temporarily a steeper downstream slope of 3 or 4:1. This done, and weirs provided elsewhere for discharging the river, the hazards of construction will be passed; but until this stage is reached the work will be subject to danger from every flood and the contingent risks will be great.

It is believed that by some such means as is outlined, subject to modifications as actual experience may prove necessary, a rock mound could be carried across the river. It should then be strengthened by completing the full-rock section.

The rock mound would be quite permeable, and the water pressure against it would vary with the volume of the discharge. To make it hold water, an embankment, which would form the real dam, the rock mound serving as its support, must be built on the upstream side. It is proposed to make the embankment of fine stone, gravel, clay, etc., with the view that a quantity of these materials should be carried well into the rock mound. An embankment composed largely of clay dumped in the water would take a much flatter slope than 3:1. For these reasons the quantity estimated by the company would have to be increased largely, and means may have to be adopted, not contemplated by the company, to render the dam tight enough to answer its purpose, as the permissible leakage is much less than the company has assumed.

By the addition of the embankment, and the retardation by friction of the flow of water through the underlying sand bed, the dam will be rendered more secure from undercutting and consequent settlement;

but some doubt as to ultimate security will still remain. Confidence would be gained to a certain extent during the construction of the dam, if no breaches were caused by the annual floods, but it would require a considerable period of time after the completion of the dam to allay all apprehension. If a site can be found where the dam can be built above a rock or other stable foundation, the permanence of the structure will be rendered much more probable and the uncertainties of construction reduced.

If such a dam becomes breached with the great volume of water standing at a high level against it, destruction would follow quickly. The crest, therefore, should be raised so far above the surface of the water in the pool that a considerable settlement could be sustained without sinking the crest below the water surface.

A study has been made to ascertain if, by the construction of auxiliary sluices at convenient points in the San Carlos ridge, the river could be in part or wholly diverted, so as to reduce the volume and velocity of flood discharge over the dam, diminish the possible risks during construction, and subsequently aid in regulating the elevation of summit level.

Following a preliminary discussion of this subject with the Board, the company has added to its estimates the cost of two sluices with openings 20 feet wide and 25 feet high; but the sills are put at elevation 64, and the river surface would therefore have to rise about 16 or 18 feet before the sluices could begin to discharge.

Furthermore, the company largely underestimates the highest possible flood at 63,000 cubic feet per second (see Chicago paper, p. 19), while the Board considers that a maximum of 150,000 is possible, and, for security, should be assumed.

The construction of sluices or other means of diverting the entire possible flow at the outset, prior to beginning work on the dam, would involve so serious a cost as to make it prohibitory; but if the sluices were so planned as to begin the relief of the dam at a point where the effect of flood discharge would become dangerous, and thereafter furnish an increasing measure of assistance, the risks involved would be reduced and construction facilitated.

After construction, the sluices could then be called upon, if necessary, to dischage a full flood.

For the purpose in question eight masonry sluices were assumed, with openings 20 by 25 feet and sills at elevation 58. The crowns would therefore be at elevation 83, and when the water surface, as raised by the dam, should reach elevation 100 the sluices would be capable of discharging the full volume of 150,000 cubic feet per second with a head of water of 17 feet over them.

As the average low-water surface of the river is at about elevation 48, the dam in the earlier stages of construction must in any case be without relief, and with the gradual raising of the mound the floods would act with increasing force and effect; but at elevation 58 the sluices would begin to cooperate.

The discussion of the balancing action of the sluices under the varying conditions of flood discharge and surface elevation of river at the several stages is complicated and quite interesting, the more so as the sluices in the San Carlos Valley are 6 miles distant from the dam in the San Juan, measuring along the river channels; but the subject is too technical for incorporation in this report.

The period of greatest danger to the dam will be when its crest is built up to about elevation 65 to 70—say, 17 to 22 feet above low water—and at this stage subjected to a flood of 150,000 cubic feet per second.

The sluices would be about two-thirds full, and be discharging about 60,000 cubic feet. The flood pouring over the dam would be about 90,000 cubic feet, the depth over the crest of the dam would be over 9 feet, and the water would descend the rear slope in a solid mass 5½ feet deep, with a velocity of nearly 13 feet per second, or nearly 9 miles per hour.

Without the aid of the sluices the depth on the crest would be about 13 feet and the velocity down the slope 25 feet per second.

These figures, though theoretical merely, may serve to give some idea of the magnitude of the destructive forces to which the rock-fill structure will be exposed and the hazards involved in the attempt to build it in such unprecedented conditions.

The cost of the sluices would not be less than $1,500,000, allowing for necessary excavations and protection for site and approaches. It may be observed that the construction of these sluices in a clay bank, to be operated under high head, will itself be no mean task, if due precautions are to be taken to insure the efficiency and safety of the structure after completion.

It may be proper to give the dimensions which the Board believes the Ochoa Dam would be likely to have, if successfully erected.

The crest of the dam at elevation 120; its base in the sand at about elevation 15; total height, 105 feet. The rock-fill portion would be 20 feet wide on top; base, 950 feet; rear slope, from 10:1 at base to 4:1 at top; front slope, 1:1. The embankment against it on the upstream side would be 20 feet wide on top (making 40 feet total width of summit) and an upstream slope of 5:1 and base 340 feet.

The volume of the rock fill would be 2,000,000 cubic yards and of the embankment 600,000 cubic yards. Total volume, 2,600,000 cubic yards; total base length, 1,290 feet.

One or more lines of sheet piling across the river under the embankment would tend to diminish the movement of water through the subjacent sand, augment the safety of the dam, and reduce leakage.

The examination of the project for the dam shows for itself its unsatisfactory character. Should further exploration develop a more advantageous site with conditions positively ascertained, a safer construction could be designed. The case is not one where unnecessary risks should be run, or plans based upon insufficient data be adopted.

With the information now available the Board can not undertake to commit itself to more than a tentative and approximate estimate of what the Ochoa Dam may cost, and the item of $4,000,000 entered in the schedule may be either increased or diminished as the conditions shall become better known.

THE SAN CARLOS RIDGE.

As an adjunct to the Ochoa Dam and the most suitable location for such sluices, weirs, etc., as may be needed to discharge the surplus drainage after construction of the dam, it will be convenient to refer to the San Carlos embankment line in connection with the main work.

The embankments proposed by the company for an assumed water-surface elevation of 106 are 23 in number, with an aggregate length of crest of about 1¼ miles; but for the greater elevation deemed necessary by the Board, viz, 110, the number will be increased to 25 and the aggregate length to 1½ miles.

There is nothing in the construction of these embankments that presents special difficulty.

The length of weir, with movable dams, provisionally estimated by the Board as needful for the flood discharge, is about 4,000 feet, which, with a head of 4½ feet, would discharge approximately 130,000 cubic feet per second. If sluices are used in conjunction, the weir length may be reduced, or possibly omitted altogether.

In any case, since upon these adjustable weirs or sluices, or both, will depend the water-surface summit elevation required, the details, when finally adjusted, must be of the most elaborate and efficient character, with ample mechanical appliances for speedy and safe adaptation to varying needs, including telegraphic communication up the valleys of the San Carlos and San Juan.

THE SAN JUAN RIVER.

The San Juan receives the surplus waters of lakes Managua and Nicaragua and of the territory draining into them, a total area that has been roughly estimated at 11,400 square miles, to which is to be added the 4,000 square miles of the river valley proper.

It is a large stream at the outset, having a flow at mean low stages at Fort San Carlos, where it leaves the lake, of 10,000 or 12,000 cubic feet per second, with a width of 800 feet and an average channel depth of 10 feet.

The total length of the river from the lake to the Caribbean is 119 miles, in which distance it falls 102 feet from mean low lake to mean sea level, with slopes ranging from less than an inch to over a foot per mile, not considering the several rapids, and an average slope of 10 inches per mile.

The navigation of the upper 50 miles is obstructed by four rapids, where rocky reefs cross the river valley, causing local steep descents of 6 or 7 feet each, and sustaining the intervening quiet stretches. These rapids, in their order, proceeding downstream, are at distances from the lake as follows: Toro, 27 miles; Castillo, 37 miles; Balas, 44 miles, and Machuca, 48 miles. At low stages the river boats can not ascend these rapids, with the exception of Balas.

From Machuca to where the San Carlos River—the most important affluent of the San Juan—joins the main stream, 65½ miles from the lake, is 17 miles of a deep, quiet stretch known as the Agua Muerte.

Three and one-half miles below the mouth of the San Carlos, and 69 miles from the lake, the company proposes to build the Ochoa Dam, the purpose of which, in conjunction with auxiliary works, is to hold back the waters of the San Juan and San Carlos and maintain the surface of Lake Nicaragua at not less than the elevation of 110 feet above mean sea level.

Just above Ochoa the canal is to leave the river and go eastward on an independent line.

With the Ochoa Dam raised to the proper height to sustain the high lake level, the San Juan Valley will be flooded for the entire 69 miles upward to the lake, and become a part of the summit level, carrying the canal navigation.

The Machuca and Balas rapids will thereby be drowned to a depth sufficient for deep navigation, but at Castillo some rock excavation in the river bed will be necessary, and still more at Toro. Trom Toro upward to the lake for nearly the entire distance of 27 miles the elevation of the river bed is such as to call for almost continuous excavation to secure the requisite width and depth of channel.

The materials to be removed are supposed to be rock, bowlders, gravel, clay, sand, and mud, in unknown proportions and practically unknown amounts.

The company proposes for its channel section through these obstructions a depth of 28 feet and a bottom width of 125 feet, with slopes in rock cutting of 1:1 and in dredgeable material of 3:1.

If 28 feet had been adopted as the standard depth, to which the several sections of the navigation should conform, there might be no compelling reason for making the river channel of greater depth, but, in fact, the company's project calls for 30 feet throughout, except in the river and in the two sea-level canals that connect directly with the harbors.

No reason is assigned by the company for making these exceptions, and the Board considers them inexpedient as reducing by 2 feet the capacity of the entire system, and that the full depth of 30 feet should be carried through from sea to sea, as in better conformity with the present and prospective requirements of commerce and the integrity of the undertaking.

Especially is this the case where, as in the San Juan, much of the excavation is in rock and other hard material.

The Board also considers that the proposed bottom width, 125 feet, for the river channel is insufficient.

The navigation conditions will be quite different from those in a canal between visible banks where the course of vessels is straightly guided, and where in passing one or the other can tie up. The deepened river channel will be submerged; it will carry whatever may be at times the maximum current, and must follow the windings of the valley through curves of greater or less radius.

Furthermore, during flood the surface currents may not run true with the channel but at some angle with it; the visible surface width will be that of the flooded valley, and for close steering vessels must rely upon buoys and such other artificial aids to navigation as may be provided.

In such circumstances a bottom width barely sufficient to enable two deep vessels to pass in a canal is quite inadequate in an open river, and for safety a single vessel even would need to proceed with great caution to avoid grounding.

In this connection some analagous data may be of service.

Colonel Childs in designing his canal for 17 feet depth made the bottom width 50 feet, but in the river the bottom width of cuts through the bars was to be three times greater, viz, 150 feet. For a canal 30 feet deep, with bottom width of 80 and 100 feet, the river channel, using the same proportion, would be from 240 to 300 feet bottom width.

For the 20-21 foot channel in the Great Lakes, through the St. Marys, St. Clair, and Detroit rivers, and the connecting waterways, intended for the use of vessels of less draft than that of war ships and ocean steamers, the minimum width of dredged waterway is 300 feet, and in bends and in difficult places this is enlarged to 400, 600, and 800 feet, those dimensions being determined by considerations of safety and reasonable speed. For continuing the lake navigation to tide water, a recently proposed ship canal, to have a depth of 26 feet, is designed with a bottom width of 300 feet.

The Board therefore considers that the San Juan River channel section should be not less than 30 feet deep and 250 feet wide, broadening around bends to 300 and 400 feet, according to degree of curvature.

There is no means of ascertaining, with any approximation to accuracy, what may be the quantities and proportions of the materials to be removed, whatever may be the cross section.

It appears that the canal company has made no surveys or examinations of the 69 miles of river between Ochoa and the lake, with the exception of a partial survey by compass, which was laid aside as valueless.

The latest information, therefore, is that obtained by the Lull expedition in 1872, when a part gradienter and part spirit-level line was run and some soundings taken. The indications of the nature and distribution of the materials composing the river bed, as furnished by the sounding lead and noted on the Lull map, constitute nearly all that is known in the matter.

The company's tabulated estimates contain items of 398,613 cubic yards of rock excavation, 422,540 cubic yards of earth excavation above water (to straighten bends), and 2,150,900 cubic yards of dredging, as representing the quantities involved in the deepening of the San Juan, and, upon inquiry as to the basis of these amounts, the company submitted a profile stated to have been derived from the Lull survey, showing the elevation and arrangement of the materials in the bed. Upon computation of the quantities indicated on the profile with the company's cross section, 28 by 125 feet, the amounts came out as rock excavation 1,424,000 cubic yards, and dredging 3,464,000. No explanation of the discrepancy is given other than the supposition that some erroneous profile must have been used, of which there is no note among the company's records.

Using the same profile as a basis with the increased cross section considered desirable by the Board, viz, 30 by 250 feet, the computed amounts are, respectively, for rock, 3,754,000 cubic yards, and for dredging, 8,526,000 cubic yards.

These figures have, in fact, no valid basis, as the profile furnished by the company is little more than guesswork, and it is not believed that the total rock excavation indicated will be required; but they do show clearly how formidable may be the cost of a proper deepening of the San Juan, and how urgent is the necessity for a thorough and reliable ascertainment of the facts.

The omission of the company to determine these seems inexplicable, especially in view of the statement made on page 3 of the final report by the chief engineer, corrected to January, 1890, as follows:

> Third. Local surveys have been made in the river San Juan at all places where the data on hand were deemed insufficient for a close estimate of the amount and cost of excavation needed, or to determine with reasonable precision the difficulties likely to be encountered in the construction of dams, embankments, or other works entering as important factors in the general scheme.

In the absence of better data it still appears necessary to use the Lull profile as a basis for an estimate, with such modifications as may otherwise suggest themselves.

Colonel Childs does not seem to have noted any rock in the river bed until near Toro Rapids, and the notes of the discarded compass survey made by the company give similar indications, so that the large rock excavation called for by the Lull profile may be much in excess.

There is another point in this connection:

The company assumes that the slope of the river surface, after being raised by the Ochoa Dam, will be three-fourths of an inch to the mile, the same as is ascribed to two of the quietest sections at low water, and, therefore, that the crest of the dam at 106 will hold the lake up to 110, with 4 feet of slope between the two. The Board has not been able to obtain any evidence of this assumed low-water slope, but this is not material, for the reason that, as elsewhere stated, the Board believes that for a reliable maintenance of the lake level at 110 the crest of the Ochoa Dam must be so raised as to secure the same or a greater elevation at that point also; in other words, that the water surface through the valley must be assumed as horizontal during the dry season.

In such case, the slope disappearing with the raising of the Ochoa Dam, there would seem to be an opportunity for a considerable reduction in the depth of excavation needed at Castillo and from Toro upward, and a recomputation of quantities from this datum, with the additional assumption that from station 4150 on the profile, above Toro to the lake, no rock excavation will really be called for, would furnish the following figures: Rock excavation, 1,722,000 cubic yards; dredging, 8,285,000 cubic yards.

Unfortunately this reduction is not permissible, for the reason that, as shown in the discussion of "Maintenance of summit level," in order to prevent the lake from rising during the wet season to such a height as would involve heavy damages to improved property bordering on its shores, it will be necessary to draw down the summit level at Ochoa to such a point as to enable the river to discharge the threatening accumulations in the lake, and, therefore, the 4 feet slope, assumed incorrectly by the company as practicable at low stages, may be imperative during high stages or, assuming the lake capable of control, during the season of heavy rainfall.

The total quantities given by Table 4 (p. 130) must therefore be used until better information is available as a means of entering the amounts in the estimates.

There are several bends in the river of such radii as probably to necessitate considerable straightening by cutting off projecting points, or the employment of special means for enabling large vessels to navigate them. There is no means of computing the amount of excavation required. The company's estimates contain an item of 422,540 cubic yards for this purpose, but the basis for this can not be ascertained. If this item be increased in somewhat similar proportion to the other data, it will appear in the provisional estimates as 1,500,000 cubic yards, which is entered as earth, although some of it may prove to be rock.

The tabulated data are given in the sheet herewith.

The disposition to be made of the large amount of material excavated from the river bed is a matter calling for careful consideration.

According to a printed specification for dredge work, prepared by the company as a basis for inviting bids, it is to be "deposited on the banks or in such places as the chief engineer may designate."

If put ashore an extra cost adding largely to the estimates must be provided for, and it is doubtful if in the upper section, where the navigation is comparatively restricted and the excavation large, it will be prudent to dump it in the vicinity of the dredged channel and within reach of the river current.

Possibly a portion of the materials to be removed is such as may be used to construct training dikes parallel with the channel, behind which the sand or other lighter material could be placed, but details of this kind must depend upon a proper survey and ascertainment of particulars.

There is a discrepancy in the stated length of the river from Fort San Carlos to Ochoa that should be noted. As derived from Childs, the distance is 68.71 miles; according to Lull, it is 69 miles. The report of 1885 and subsequent reports put it at 65.50. As no survey was made later than Lull's, the earlier figures should be taken.

ESTIMATES OF EXCAVATION IN SAN JUAN RIVER BETWEEN OCHOA AND FORT SAN CARLOS.

Company's cross section.

[Depth, 28 feet. Bottom width, 125 feet. Slopes, rock, 1:1; dredgeable material, 3:1. Slope of 4 feet assumed from Fort San Carlos to Ochoa.]

TABLE 1.—*In company's estimates.*

	Cubic yards.
Rock excavation	398,613
Dredging	2,150,900
Total	2,549,513

TABLE 2.—*As actually computed from company's profile.*

	Cubic yards.
Rock excavation	1,424,000
Dredging	3,464,000
Total	4,888,000

TABLE 3.—*Board's cross section.*

[Depth, 30 feet. Bottom width, 250 feet. Slopes, rock, 1:1; dredgeable material, 3:1. Bottom width increased in bends to average of 350 feet. Slope of water surface assumed as above.]

	Rock.	Dredging.
	Cub. yards.	*Cub. yards.*
Castillo cut, station 3325 to 3412	123,000	....
Toro Rapids cut, station 3740 to 4150	2,076,000	517,000
Above Toro Rapids, station 4150 to 5317	1,555,000	8,009,000
Total	3,754,000	8,526,000

TABLE 4.—*Computation as in Table 3, with assumption of no rock in river bed above station 4150.*

	Rock.	Dredging.
	Cub. yards.	*Cub. yards.*
Castillo cut, station 3325 to 3412	123,000	....
Toro Rapids cut, station 3740 to 4150	2,076,000	517,000
Above Toro Rapids, station 4150 to 5317	....	9,646,000
Total	2,199,000	10,163,000

Earth excavation required to cut off bends.

	Cubic yards.
Company's estimate	422,540
Provisional estimate by Board	1,500,000

LAKE NICARAGUA.

The southeastern end of the lake, near Fort San Carlos, where the San Juan River leaves and the Frio enters, is a shallow expanse, deepening gradually with a flat bottom slope. The company's map indicates that the 30-foot contour of depth, with the lake at elevation 110, lies 14 miles offshore, and a ship channel of this length is to be dredged on a straight line, bearing about north 70° west from the San Juan outlet.

As proposed by the company, the channel will be 30 feet deep and 150 feet wide on the bottom, with side slopes of 3:1.

On this basis the company's estimated amount of dredging is 4,726,076 cubic yards, but there is some error in this, as the amount stated corresponds more nearly to a bottom width of 125 feet, and the actual amount as recomputed is much greater, viz, 5,645,000 cubic yards according to the company's profile, or 5,143,000 cubic yards according to the company's chart.

For reasons stated in discussing the width of the river channel the Board is of opinion that the bottom width of the lake channel should be not less than 300 feet. The course of vessels, although straight, is in the open lake subject to such irregular currents as may exist in so large a body of water and to the action of the winds. The information on this point is that storms are infrequent, although squalls of no great violence or duration occur, and that the prevalent wind is moderate to fresh and a continuation of the east-northeast trade from the Caribbean.

The proposed side slope of 3:1 is also quite inadequate.

The material composing the bottom is on top a liquid mud, stiffening downward into harder mud or clay. The Board made soundings along the channel line from a point about 5 miles out in the lake, toward the San Juan outlet, and at intervals of about a mile took means to thrust a long pole into the bottom, with the following results: At 5 miles out, depth of water 10 feet, depth of mud 8 feet; at 4 miles, water 9 feet, mud 9 feet; at 3 miles, water 8 feet, mud 9½ feet; at 2 miles, water 7½ feet, mud 9 feet, and at 1 mile from shore, water 6 feet, mud 11½ feet. The mud was noted as soft and gritless, a derivative of volcanic ash or the like, probably mixed with more or less vegetable matter.

Such material as this could never stand at the submerged slope of 3:1, particularly as the currents due to the action of vessels' screws are very destructive to channel banks.

The closest analogy to work of the kind proposed is to be found in the dredging in Mobile Bay, where a ship channel of 24 feet depth, with a bottom width of 280 feet, has for many years been in course of construction, and the physical conditions are quite comparable with those in Lake Nicaragua. The Mobile channel has a total length of some 23 miles, and the underwater slopes assumed by the different materials dredged through are as follows: Very hard sand, 3:1 and 4:1; hard sand, mixed with shell, 6:1 and 8:1; stiff mud, 8:1 and 12:1; soft to liquid mud, 14:1 and 20:1.

The description of this soft mud, as given by the engineer officer in charge, to whom the Board is indebted for these and other particulars, "a thick soup underlaid by a stiff mud," is precisely applicable to the greater part of the Lake Nicaragua material.

The Board therefore considers that an assumed slope of 10:1 is a very moderate datum for computation. Using this, and a bottom width of 300 feet, the quantity to be dredged according to the company's profile is 12,873,000 cubic yards, and as computed from the company's map 11,724,000, an average of 12,300,000, and this is more likely to be exceeded than reduced unless some means be taken to maintain the channel banks from inflow of adjacent material. Sheet piling would do this, and reduce the cross section, but for so long a channel it would be a costly item, and it seems likely that this may be avoided by following a Dutch practice and depositing the stiffer material excavated from the bottom of the cut so as to form a submerged wall or bank parallel with the channel which will crush down through the semiliquid mud and hold it back. Beyond this, half a mile or more from the channel, the softer mud can be pumped by means of hydraulic dredges. With this method of protection, however, it would not be prudent to diminish the cross section of the channel.

Channel dimensions and estimated quantities are given in the following table:

Estimate of dredging in Lake Nicaragua from Fort San Carlos to the 30-foot contour with the lake at 110.

COMPANY'S CROSS SECTION.

[Depth, 30 feet. Bottom width, 150 feet. Slopes, 3:1.]

	Company's estimate.	Actual computation.
	Cubic yards.	*Cubic yards.*
From company's profile	4,726,076	5,645,000
From Maxwell's chart	....	5,143,000
Average	....	5,400,000

BOARD'S CROSS SECTION.

[Depth, 30 feet. Bottom width, 300 feet. Slopes, 10:1.]

	Board's estimate.
	Cubic yards.
From company's profile	12,873,000
From Maxwell's chart	11,724,000
Average	12,300,000

Beyond the dredged channel the sailing course is through the open lake for a distance given by Colonel Childs as 56½ miles to the west coast, leaving Balsillas Islands to the northward and the Solentiname and Sonate groups to the southward, and passing about 4 miles to the southward of the island from which rise the volcanoes of Madera and Ometepe. This island has a total length of 20 miles, its northwest end about 5 miles and its southeast end about 11 miles distant from the west coast, sheltering the canal entrance from north-northeast to east by south from the prevalent winds coming from about east-northeast.

This continuation of the trade wind is represented to blow steadily, with a force from gentle to fresh, during the greater portion of the year. The strongest winds are said to be from the north and west of north. Their force can not in any case be great, as is proved by the endurance of the frail, half-filled timber cribs, the construction and condition of which was noted by the Board, which compose the landing piers at San Jorge, 4½ miles north of the canal entrance, and at Granada, near the northwestern end of the lake, 50 miles distant, where the exposure is about the same.

Under the lee of the islands is an admirable harbor for vessels of all draft, with good holding ground and entire shelter.

THE CANAL ENTRANCE ON THE WEST SIDE OF LAKE NICARAGUA.

The west shore of the lake is rocky, and considerable excavation will be required to carry 30 feet into the canal, the contour of that depth, with the lake at 110, lying about 1,600 feet from the shore line. The canal entrance is on the lee shore, and while the exposure is not great, it may be desirable to protect it by artificial works. The company proposed for this purpose two piers, starting from the sides of the canal, and extending into the lake on diverging lines to a length, respectively, of 1,800 and 2,400 feet, the entrance width at the outer end of the shorter pier being 600 feet. This funnel-shaped entrance is not desirable in circumstances of this kind as tending to accumulate such sea as may be running shoreward, and the Board considers that it would be preferable to separate the piers at the shore ends, placing them 800 or more feet apart, and converging the extremities to about 500 feet for the entrance width. These piers may be built of crib work, filled with stone derived from the local excavation, which is in ample quantity for that purpose. In addition to these, additional short guide piers of timber work, about 400 feet in length, would be required to sustain the canal banks where they pass through the shore line.

The amounts estimated by the company are sufficient to cover the cost of these constructions.

THE WESTERN DIVISION—LAKE NICARAGUA TO THE PACIFIC.

LAKE TO TIDE LOCK NEAR BRITO.

The territory separating the lake and the Pacific has been quite thoroughly explored in the course of the several surveys made at various times, and the Lajas-Rio Grande route, originally selected by Colonel Childs in 1850 and now adopted by the canal company, doubtless offers on the whole the greatest advantages. The country is open and rolling, with moderate elevations, and presents no serious obstacles to canal construction.

The canal line leaves the lake shore 900 feet north of the mouth of the river Lajas on a course south 60° west up the valley of that stream, crossing the river four times within a distance of 1½ miles. For the greater part of this distance a new channel is to be made, to divert the river to the south side of the canal, and prevent interference with it. Westward of the last crossing, the river valley bears more to the southward, while the canal continues through an open country across a gradually ascending plain toward the summit of the divide. After some curvature, the summit is reached, 5 miles from the lake, at an elevation of 154 feet above mean tide, or 44 feet above the summit-level elevation 110, that is to be maintained in Lake Nicaragua, giving a maximum depth of cut of 74 feet.

Passing the summit the line enters the drainage basin of the Rio Grande and meets the river at a distance of 7½ miles from the lake, at the head of a narrow valley or gorge, and thence follows the general course of the stream to the Pacific at Brito. This portion of the route is heavily timbered. In the gorge, which is 1¾ miles long, the line is mainly in curves, with a minimum radius of 4,300 feet. Of the whole distance from the lake to the Pacific about two-thirds consists of tangents and one-third of curves, with radii of from 4,300 to 17,000 feet.

The width of the gorge is insufficient to furnish separate accommodation for both canal and river. This complication led Commander Lull, in 1872, to seek a separate route, and he adopted a line which leaves Lake Nicaragua 3½ miles to the northward of the mouth of the Lajas, and, following the valley of the Medio and one of its small tributaries, crosses the divide with an elevation of 243 feet above mean tide, and then joins the Lajas line at the western end of the Rio Grande gorge. By this route the water of the river could be kept in its own channel by making a few cut-offs, but it had no other important advantage, while the depth of the divide cut and the amount of excavation were much greater. The company has adopted the Lajas line, returning to the Childs location.

From the outlet of the gorge, two alternative routes have been located by the company—the earlier one continuing the canal to the sea, the other damming the Rio Grande 3½ miles from the Pacific for the formation of a large basin, which would prolong the summit level 4½ miles westward.

By the first route, called the "low-level line," the canal in excavation and embankment follows the right bank of the Rio Grande through the gradually sloping valley to Brito, descending by four locks, placed at natural sites, or, in their absence, where the natural slope of the valley requires; the first lock (designated 4A), with a descent of 25 feet, terminating the summit level, is placed in a hill at the west end of the gorge, 9.2 miles from the lake shore; the second lock (5A), with a descent of 30 feet, is placed in the valley at a farther distance of 1.6 miles or 10.8 from the lake; the third lock (6A), also with a descent of 30 feet, is 3.6 miles farther, or 14.4 miles from the lake; the fourth, or tide lock (7A), with a descent of 25 feet at mean tide, or 29½ feet at ordinary low tide, is 2 miles farther, or 16.4 miles from the lake. The distance from the tide lock to the 30-foot contour in the Pacific is 1.3 miles, and the total distance from the lake to this depth is 17.7 miles.

West of the summit level the Rio Grande has no important tributaries on its left bank. On its right bank it receives the Tola, which has its sources some miles to the northward. The Tola is ordinarily an insignificant creek, quite dry at times, but its sources are in the hills, and occasionally it becomes a torrent. Unfortunately it has never been gauged, and even its drainage area is not known; it is probable, however, that its discharge is at times as much as 3,000 cubic feet per second, and possibly much more.

The canal line as located crosses the Tola a short distance above its mouth, and the disposition of the flood waters has been considered a matter of some difficulty; this apprehension, and the advantages which would result from the extension of the summit level toward the Pacific, with the formation of a wide basin in the valley of the Rio Grande, have led to the adoption by the company of the alternative "Tola Basin line."

At a place called La Flor, 3.8 miles from the Pacific terminus and 13.9 miles from the lake, the valley of the Rio Grande is narrowed by two steep hills to a width, on the valley floor, of 1,600 feet, at an elevation of 40 feet above mean tide, and a width of 2,000 feet between the summit-level contours of elevation 110. The company proposes to build a dam at this point of sufficient height to raise the water to elevation 110, thus extending the summit level, as already stated, to within 3.8 miles of the Pacific, forming a capacious basin of some 4,000 acres in the valleys of the Rio Grande and Tola. This arrangement would facilitate navigation by substituting a basin for 4.6 miles of canal, and would solve the question of the disposal of the flood waters of the Tola by permitting their free discharge into the basin.

As originally designed, the La Flor or Tola Dam, as it is indifferently known, was, like the Ochoa Dam, to be a "rock fill," and to be constructed in the same way, with a weir on the crest for the discharge of the Rio Grande drainage.

This plan has been modified more recently by providing a solid concrete core for the dam, backed with a stone and earth embankment on both sides, and locating a weir in the saddle of an adjacent hill.

This weir is to discharge the drainage of the valley and, as the Board is lately informed, about 60 per cent of the surplus discharge of the lake watershed also.

The question as to what disposition to make of the drainage during the construction of the dam or its masonry core has not yet been fully considered by the company.

The La Flor Dam, per se, is a much more formidable construction than that proposed at Ochoa, in regard both to its volume and the head of water it has to sustain. The river channel cuts about 20 feet into the general surface of the valley, and the contour of elevation 20 feet above mean tide crosses its bed immediately below the site of the dam. During the dry season the river runs dry, and the surface of the ground water is below the bed, as would be the case also below an impervious dam. It follows, therefore, that the head of water against the dam would be fully 90 feet, and it hardly need be said that only the best material is admissible for the foundation of a dam under such a pressure, and where such vast interests depend upon its integrity. The foundation should be solid rock, free from fissures or seams, or, at the least, a core wall should be carried down into such material if accessible.

In 1892 and 1893 diamond-drill borings, 26 in number, were made along the center line of the dam and at several points within 400 feet of it, with very discouraging results. A mass of sand, gravel, and mud was found on the center line extending 75 feet below the floor of the valley, or 35 feet below sea level; several borings passed through materials below this level, reported as " coarse sand," "yellow clay," " clay and rock in layers," " yellow clay and sandstone," etc., to depths reaching 150 feet below sea, and among other borings taken was one 400 feet above the center line and close to the area to be covered by the dam, in which the material, from 40 to 214 feet below sea, was "clay, sand, and pieces of rock," followed by 30 feet of "telpetate" (a soft, clayey, volcanic rock), and 54 feet of "white clay with pieces of rock," and the boring was ended in this material, 298 feet below mean tide, or 338 feet below the surface of the ground, without having encountered any solid material.

If such are the facts, the Board deems the project of a 90-foot dam impracticable, and omits consideration of its construction. It may be pointed out that, in any case, the advantages to be expected from the dam are no more than the substitution of 4.6 miles of basin for an equal length of plain canal and the disposal of the flood waters of the Tola, and these benefits are not of such magnitude or urgency as to justify an attempt to secure them at any such risk as the construction of the dam would involve.

It should be stated that the unfavorable results of the borings at La Flor are in part, at least, recognized by the company, which, nevertheless, is unwilling to abandon the plan of the dam and basin on the present evidence in the hope that additional borings may be more favorable. It is difficult to see what foundation there is for such a hope. The engineer who had charge of the borings was reputed to be, and his notes and report indicate strongly that he was, careful and competent, and the facts as observed and reported by him seem fatal to the plan.

If the views of the Board are correct, a return must be made to the low-level plan—a canal in excavation and embankment. The only serious objection to the company's location of this relates to the disposal of the floods of the Tola. It would probably be necessary to receive this water into the canal and to discharge it over a weir at some convenient place on the opposite side, whence it would pass into the Rio Grande. The current in the canal caused by this flood would probably not exceed

1 foot per second, or seven-tenths of a mile per hour, but there is some uncertainty about this, as the Tola has not been gauged, and its maximum discharge is not known, and proper gaugings may show that it is underestimated.

From examination of the topography the Board finds reason to believe that a canal line can be carried down the south side of the valley without any special difficulty, and so avoid all interference by the Tola.

A map location indicates that the line will be shorter, and two or three diversions of the Rio Grande channel will keep the river entirely to the north of it.

The cost is somewhat greater by reason of more excavations, but it may be worth this to be free of the Tola discharge.

Both locations should be thoroughly studied and selection made of the better. With present information the Board prefers the southern route, and its estimate is made for that.

If this modification were carried out it would be advisable to change the location of Lock 4A to a new site 500 feet southward; to build a weir at the former lock site, to discharge the water of the upper Rio Grande, and to close the remainder of the valley, here quite narrow, by a dam at the west limit of the summit level; the head of water to be sustained by the dam would be only 30 feet; it would be founded on the so-called "telpetate," and have to be sunk well into it to make the foundation secure, but with the moderate head of water no great difficulty would be met.

As the flow of the upper Rio Grande must be taken into the canal at the head of the gorge the effect on navigation of the introduction of its floods must be considered.

The area of the company's standard canal section in earth is 3,696 square feet; the flow of the stream at high floods has never been gauged, and is not known. It was estimated by Colonel Childs at 5,670 cubic feet per second, but this may be exceeded. If this amount of water were to pass westward through the canal it would produce a velocity of 1.5 feet per second. If, on the other hand, no water were allowed to pass the weir at Lock 4A the river discharge would be compelled to find an outlet through the canal eastward into Lake Nicaragua, producing a current of 1.9 feet per second or more in the divide cut, where the area of the cross section (in rock excavation) is 3,000 square feet. In that confined section this current would be undesirable; but it is evident that the weir at Lock 4A can be so regulated under intelligent supervision as to cause a division of the discharge of the river at the head of the gorge, part going westward to the Pacific, the remainder eastward to the lake, and the current in both sections limited to so low a rate as to be harmless.

The disposal of the water of the upper Rio Grande being thus provided for, it seems unnecessary to carry out the company's project of diverting it by an expensive dam across the upper valley and the construction of an artificial channel and embankment across the dividing ridge into the valley of the Lajas and thence into the lake.

The company's proposition to discharge through the canal into the Pacific a large part or any part of the surplus water of the lake watershed would be objectionable for reasons above indicated; and, in general, the use of a canal as a drain should be avoided when practicable.

For the first 1½ miles from the lake, where the canal line follows closely the general direction of the river Lajas, the average elevation of the ground is little above the proposed lake level. The company proposes to make this section 120 feet wide at bottom, for use as an extension of the harbor and a passing place for vessels; but it appears to the Board, as in the case of the canal from Greytown, that this width is insufficient for the meeting of two vessels and more than necessary for the movement of one. If a suitable passing place were formed at the west end of this section, long enough to receive three or four vessels, and the bottom width eastward to the harbor reduced to 100 feet, the cube of excavation would not be changed materially, while the work would serve the purpose better.

The material from the western crossing of the river Lajas to the eastern crossing of the Rio Grande, a distance of 6 miles, covering the west divide, is principally volcanic rock, of all degrees of hardness, from "telpetate" to the so-called "conglomerate." In a frosty climate "telpetate" would disintegrate rapidly; even in the mild climate of Nicaragua it is found more or less disintegrated wherever exposed. Conglomerate is usually hard rock resembling trap, and while its excavation would be more expensive, the sides of a cut formed through it would be more permanent. Borings—19 in number—have been taken with a diamond drill, at intervals of about 1,000 feet, through the heaviest work; after passing through earth of an average depth of 12 feet, rock was reached and penetrated to the grade of canal bottom. The cores obtained by the use of the diamond drill would have been valuable if preserved and properly arranged, furnishing a complete record of the material passed through, but only a few of them, representing the harder rock traversed, are now to be had. Many cores were left on the ground, where fragments are still to be found, showing much disintegration.

The company's standard canal cross section, in rock, has vertical sides from the bottom to 10 feet above water, where there is a berm of 5 feet; above this the slope is 1 horizontal to 5 vertical.

Considering the nature of the rock, it seems probable that these slopes can not be maintained throughout the cut, and in such case the amount of excavation will be greater than estimated, but in the absence of more definite information there is no means of providing for what may prove to be the necessary increase except by a more liberal allowance for contingencies.

In the estimate of 1890 the company assumed that all of the locks of the western division would be founded on rock, but borings made in 1892, at the site of the tide lock, showed a deposit of mud of unknown depth extending at least 37 feet below lock bottom, and in the estimates of 1895 an additional sum of $250,000 is entered for foundations. A less difficult site can without doubt be found. At the site of the second lock from the lake, on the low-level line, no borings have been taken except with an earth auger, and the existence of rock at the elevation reported is doubtful. Rock of some kind has been found at the remaining sites on both lines.

It is believed by the Board that the arrangement of locks proposed by the company, which gives the summit lock a lift of 25 feet, while the tide lock has a lift of 29½ feet, should be changed. In locking down to the sea level certain disturbances caused by difference in specific gravity of salt and fresh water will delay the operation of the tide lock, and it will be judicious to reduce its lift. The Board, therefore, would modify the project to give this lock a lift of 24½ feet at mean low tide, the three others having 30 feet each. There results a considerable increase of excavation in all the levels between the summit and tide locks, the cost of which is belived to be justified by the increased efficiency gained.

The company, for some reason not stated, has left the depth in the canal between the tide lock and Brito Harbor at 28 feet, although the canal above the lock and Brito Harbor itself are to be excavated to 30 feet. The exception made is inexpedient, and the full depth should be made continuous and provided for in the estimates. The Board's estimates include this.

It is proposed to place a guard gate in the divide cut to shut off the water of the lake, should it be desired at any time to draw the levels to the westward. There are no detail drawings or computations for the gate, and the company's estimate of its cost is entered in the schedule.

A single-track narrow-gauge railroad is provided from the lake to Brito for the transportation of supplies, etc., and particularly for conveying stone from the west divide to the breakwater at Brito Harbor; no sidings, stations, machine shops, or other necessary adjuncts are included. The Board has no doubt that a double-track standard-gauge railroad will be required and should be provided, with the common and necessary facilities for operation and maintenance, and has increased the estimate accordingly.

BRITO HARBOR.

The Pacific terminus of the canal, as originally selected by Colonel Childs in 1852 and adopted by the Lull expedition in 1872 and later by the present canal company, is at Brito, where the alluvial and heavily timbered valley of the Rio Grande reaches the coast line.

The ranges of hills confining the valley run to the shore and form headlands about 1½ miles apart, connected by a straight stretch of sand beach having a compass direction about east-southeast. The westerly headland projects some 1,500 feet into the sea as a bold, rocky promontory, under whose partial protection from the heavy pounding of the surf the river discharges with a width of 100 feet and a low-water depth through the sandy foreshore of 2 feet, the range of the tide reaching to nearly 9 feet.

Examination of the sea chart shows that the general trend of the Nicaraguan coast line is northwesterly, and that the offshore slope of the ocean floor is quite decided, a depth of 24 fathoms being reached abreast of Brito at about a mile from the land and 34 fathoms at something over 2 miles.

Eight miles down the coast, southeastward from Brito, is the small natural harbor of San Juan del Sur, and 12 miles farther the bay of Salinas deeply indents the coast line.

About 27 miles due south from Brito is Cape Ste. Elena, the terminus of the large promontory that partly shelters Brito and the intervening coast from the southward.

The main exposure of Brito from the sea, therefore, is through the arc between south-southwest and west-northwest, and the proximity of the deep-sea contours, with the full width of the Pacific beyond, renders the possibilities involved in this exposure quite as formidable as at any point on our own coasts where the construction of harbors and breakwaters has been undertaken.

Either San Juan del Sur or Salinas offers much greater natural advantages as a harbor, and the several canal explorations sought vainly to connect one or the other with the lake, but found the intervening elevations of the coast range too great and the descent on the Pacific side too precipitous.

The exigencies of canal construction and water supply for summit level were controlling considerations, and seemed to leave no choice but to make the best of Brito as a terminus.

Fortunately the prevalent winds are off shore in continuation of the northeast trades across the isthmus, and the indications are that storms from the area of exposure are comparatively infrequent, but the long, heavy swells of the Pacific run shoreward in the calmest weather and produce a nearly constant surf with breakers from 4 to 10 feet and over in height. As is the rule where the action of special storms is absent, the general direction of wave approach is normal to the shore line, and therefore the alignment of any breakwater or covering work designed to protect the harbor from sea action should be approximately parallel with the shore, and its development such as to shield the entrance as effectually as may be, without making it unduly narrow or tortuous.

Furthermore, the passage should not be too close to the beach, as, with long high waves, the send of the sea is an element of danger in too contracted a fair way for a vessel entering at an angle with the wave course.

The earliest plan for a harbor at Brito was that of Colonel Childs, as published in his report of 1852. He was an expert canal engineer, but took occasion to excuse himself for such defects as might be found in the harbor plans on the ground of lack of experience in designing works of this character.

The entrance, 400 feet in width, with a depth of 27 feet at mean tide, was protected on either side by rubblestone and masonry piers, one extending from the shore line, the other from the adjacent rocky promontory, and the harbor was to be constructed by excavating into the land with a right-angled bend after passing the shore line, to a distance of two-thirds of a mile from the entrance.

The harbor area, with a depth of 17 feet at low water, for which the navigation was designed, was some 35 acres, with a total water area of about 50 acres.

The principal technical defect in this project is that the entrance opens directly seaward, nearly on the line of wave approach and maximum exposure.

With the open mouth, the harbor as designed, even in ordinary circumstances, would be in a state of chronic agitation, the operation of the tide lock, although two-thirds of a mile inland, would be seriously interfered with, if not endangered, and a heavy storm would probably destroy the harbor works entirely.

Colonel Childs considered that with the limited area it would be inadvisable to permit the Rio Grande, with its variable flow, to discharge through the harbor, and therefore made provision for a separate artificial channel to the eastward.

The estimated cost of the harbor project, including wharfage, crib work, lights, and other necessary constructions, as also an item of $8,000 for the diversion of the river, was $2,700,000.

The harbor as designed in the 1874 report of the Lull expedition was an improvement upon Childs's, so far as the entrance was concerned, a breakwater 1,000 feet in length, as shown on the plan, or 1,200 feet as stated in the text, being projected southeasterly from the end of the promontory across the harbor front, with an auxiliary jetty extending 350 feet perpendicularly from the beach well under cover of the main work. The total water area measured shoreward from the breakwater was to be about 80 acres, of which 36 would be excavated out of the land, and the harborage with a depth of 26 feet would be 67 acres.

Two serious defects were introduced. The entrance width of 1,100 feet was too great, and, notwithstanding the shelter of the breakwater, would admit heavy seas, involving excessive agitation in all parts of the basin, and the tide lock placed at the back of the harbor was only a quarter of a mile from the entrance, and its operation and security would have been impracticable.

The cost of the harbor and adjuncts, including $9,500 for the diversion of the Rio Grande, was $2,347,000.

In a valuable paper printed in the annual report of the Coast Survey of 1874, which gives most of the few known physical data relative to the harbor, Prof. Henry Mitchell, discussing these conditions, urges that the harborage for a 26-foot navigation was too restricted; that with the works as proposed the 10-foot sea observed by him would create a 5-foot sea inside, and recommends a deeper extension into the land, and the construction of a double basin in order to secure more accommodation for vessels and greater tranquillity at the canal entrance.

The plans of the canal company are intended to provide for 29½ feet depth, and the excavations and dredgings in the harbor are to be made to this depth below low water, equal to 34 feet below mean sea level, the datum plane of reference.

On two points Professor Mitchell's suggestions have been followed. The harbor area has been increased 50 per cent—from 67 to 103 acres—and the tide lock has been moved inland along the line of the canal to a distance of over a mile from the shore line, but the defects of the Lull entrance have not been corrected, and, in some respects, have even been increased.

The entrance has been narrowed from 1,200 to 800 feet, which dimension, in view of the sea exposure and prevalent wave action, may be regarded as judicious, by increasing to about 800 feet the length of the auxiliary shore jetty that limits and protects the harbor on the east side, but in order to gain harbor space this jetty has been moved bodily 200 yards or more eastward down the beach, and at the same time, as an offset to the lengthening of the jetty, the breakwater projecting from the promontory has been shortened to 900 feet.

The effect of these two changes is that the main work no longer overlaps the entrance and reflects the advancing waves, but for a width of about 200 yards measured transversely to the line of wave approach permits a free run of the sea directly into the harbor.

Another grave defect is to be noted. As originally designed, the harbor lines to the westward were curved back nearly to the river bed, skirting the hills on that side, but some earth-auger borings made in 1888, and at various points of the area to be dredged, disclosed the unwelcome fact that extending out from the rocky spurs nearly to the middle of the harbor and directly opposite the entrance the rock lay from 9 to 15 feet only below the surface of the ground. As the removal of this submerged rock to 34 feet below mean sea level would be a costly matter, the harbor lines were drawn in so as to exclude it altogether. This diminution in harborage is undesirable, but the more serious aspect of the matter is that, with an entrance two-thirds open to the sea, and depths of 30 and 40 feet at low and high water, a vessel seeking entrance would find itself confronted with a rocky shore less than 1,200 feet distant, upon which a heavy surf was breaking.

It is quite certain that these are conditions incompatible with the sense of security and freedom from apprehension of peril that the master of a vessel should feel in bringing his ship into port.

Either the submerged reef must be removed altogether, or the plan of the harbor be so modified as to make its removal unnecessary, at least for the present.

In any case the main protecting work must be so extended as to cover the entrance, and, since this is to be done, it may be expedient to lengthen the breakwater sufficiently to enable the entrance to be shifted far enough eastward to obviate the immediate necessity of excavating the rock.

The cost of the harbor, according to the latest estimate by the company, is put at $1,720,000. The amount of rock contained in the submerged reef to 30 feet below low water may be roughly inferred from the scanty boring data at about 500,000 cubic yards, which would cost perhaps $2,500,000 or $3,000,000 to remove. This sum would equal the entire cost of a properly designed breakwater, and its expenditure for that purpose be productive of much greater benefit than if applied merely to interior excavation.

A preliminary project to accomplish the several necessary ends is indicated on the accompanying plan. The breakwater is extended to 3,600 feet in length, parallel with the beach, and terminates in 10 fathoms, a depth by no means unusual in deep-sea constructions of this kind, and not to be avoided in the present case.

The shore jetty, with a length of 800 or 900 feet, reaches the 6-fathom curve and leaves an entrance 800 feet in width protected from any bearing west of south, and vessels may enter on a north-northwest course with an adequate margin of safety from the heads of the works on each side.

The area of deep dredging to 30 feet below low water, for the present at least, may be limited, as shown, to 100 acres, leaving the remainder of the area protected by the breakwater to be excavated later, if found desirable.

It is not believed that entire quiet will be secured in the basin, since the advance and recession of the wave action from the ocean surface adjacent to the entrance must in part be transmitted inward, and, in order to secure such tranquillity as is desirable for vessels lying at a wharf, whether for repairs, for coaling, or handling cargo or ballast, or waiting lockage, and for the security of the tugs that will lie in the harbor in readiness for service, an inner basin is provided, with a length of 2,400 feet and a width of 400 feet. The inner basin has a narrowed entrance from the outer basin, and the canal line passes directly through it, leaving a free passage with space on both sides for stationary vessels.

This project is regarded as substantially in conformity with the general conditions of the locality so far as they are at present known and understood, but must, as to details, be considered tentative and provisional.

The information available is not sufficient to enable final plans and estimates to be made.

The borings made under the company's directions are too few in number and of too little penetration to determine the underlying materials within the harbor limits. None of these reached the projected bottom of the harbor, and the actual distribution of materials and particularly the extent of necessary rock excavation are not known.

In addition to the borings, which should thoroughly explore the areas in question, so as to leave no doubt as to the nature and disposition of the submerged materials, and so form a basis for a reliable estimate for construction, other information is needed for the preparation of a final and satisfactory project.

None of the charts of the harbor, since that of Childs, give the plane of reference to which the soundings are reduced, and a doubt exists as to the actual position of the contours. The hydrography should be revised and extended to include the vicinity of the harbor on both sides, observations of waves and currents should be made, and some data obtained as to the direction and force of the winds, and particularly those of such storms as are liable to affect the harbor. The ocean bed, where it is proposed to build the breakwater and jetty, should be investigated in order to estimate the depth to which the rock masses would sink, and so increase the total quantity required. The Board's hypothetical estimate assumes a subsidence of 6 feet, but this may be exceeded.

The character of the rock constituting the adjacent promontory should be definitely ascertained in order to determine if it is suitable for breakwater construction in the large masses requisite in this case. The earlier projects used this rock, but in his paper Professor Mitchell expressed a doubt as to the expediency of doing so, and the company's project takes the rock from the western divide, which is believed to be of tougher texture.

It may be that thorough investigation would show that neither material would possess the requisite endurance or be economically procurable in blocks of the necessary weight to resist the tremendous pounding to which they would be exposed, and that the construction of massive concrete blocks to cover the surface would be required to secure proper stability, in which case the estimates would need considerable modification.

Gaugings should be made of the Rio Grande, observations of its varying stages and volume, the duration of its floods, and the velocity of its flow, in order to determine if the river can be permitted to discharge through the harbor, or if it would be expedient to construct a separate channel for it—not altogether a simple task, since it must discharge through a sandy beach and into a heavy surf.

The company's estimate makes no provision for anything beyond actual harbor construction, with the exception of an item of $12,500 for lights and buoys, which is obviously insufficient.

Considering the character and extent of the commerce invited to use the canal, the length of voyage to reach it, and the nature of the locality, nothing less than a light of the first order established on a promontory would be suitable, and this as a coast light would need to be supplemented by pier-head lights on each side of the entrance. A pair of small range lights at the head of the harbor to mark its axis and sailing line would also be required, and a line of buoys to mark the western limit for deep navigation. The inner basin and its connection with the outer basin will also need lights.

There should be some provision for wharves. Vessels making long ocean voyages are always in need of repairs, refitting, coaling, supplying, etc., and even if all that is necessary in this respect is not furnished, there should at least be wharves where vessels may lie, a machine shop for repairs, and other similar arrangements.

ADDITIONAL SURVEYS AND EXAMINATIONS.

Somewhat frequent reference has been made in this report to the need of more specific information before a satisfactory final estimate of cost of the company's project can be prepared. It may be desirable to give a summary of the several items with reference to their localities.

1. *Brito Harbor.*—The harbor should be surveyed, its hydrography ascertained, the coast line for a mile on each side located, and exploration made of the ocean bed to ascertain the probable depth to which

the stone deposits for breakwater construction would sink. The borings made by the company with an earth auger inside the shore line report indications of rock. These may be in error. New borings should be made by which the nature of the subjacent material can be fully ascertained, in order to determine what kind and quantity of excavation is necessary, and should a large amount of rock be found, the harbor should be moved southeasterly, as has been indicated on the map in the position representing the Board's present judgment as to location.

2. *Western division.*—A new location is necessary from the summit lock, 9¼ miles distant from the lake, to the Pacific, following the left bank of the Rio Grande instead of the right bank, according to the present line. It is believed that such a line can be located, not differing greatly in cost from the other, by which the crossing of the Tola and La Flor creeks on the north side of the valley can be avoided, as well as the diversion of the upper portion of the Rio Grande, which is regarded by the company as necessary to avoid interference with the canal. The left-bank line in question is indicated by a dotted line on the Western division map, which accompanies this report.

3. *Lake Nicaragua.*—The sailing line from the mouth of the Lajas, on the west shore, to Fort San Carlos, at the San Juan outlet, should be sounded out and the route mapped by triangulation across the lake, using the adjacent islands as stations. The entrance on both sides should be carefully developed by soundings, and the materials to be excavated definitely determined. The area between Ometepe Island and the canal entrance should be fully surveyed, as it is the natural harbor for vessels lying at anchor.

4. *San Juan River.*—The improvement of the San Juan constitutes one of the most costly items of the entire project, and the information available for defining the channel improvement and estimating quantities of the several materials is extremely scanty. No survey of the river has been made since that reported by the Lull expedition in 1872. No explorations of the river bed have been made, and little is known of its constituent materials. Borings are necessary, particularly in places where rock is known or suspected to exist, and the investigation should also keep in view the ascertaining of how best to dispose of the surplus excavations. Below Machuca Rapids thorough exploration should be made for an eligible dam site as a substitute for that of the present Ochoa Dam, and below the San Carlos similar investigation should be made as far down as to include the region of the Serapiqui. As will be noted hereafter, the survey of the river should be continued down ward, including exploration for low dam sites to below the outlet of the San Juanillo, with a view to the possible canalization of the river to that point.

While in Nicaragua the Board took occasion to make a preliminary investigation of this kind, and the results indicated in the accompanying report by Mr. F. P. Davis are not unfavorable to the possibility of finding a practicable line by which the flow of the San Juan could be checked in that vicinity. The report has value otherwise as giving some idea of the practical difficulties of surveying in those regions.

5. *Eastern division from Ochoa to Greytown.*—The topographical work by the company for the location of the eastern division along the line adopted has been thoroughly done, and little more work of this character is required; but while topography is an indispensable basis for canal location, it constitutes the groundwork merely, leaving vitally important hydraulic and other data to be gathered and studied before

final location and construction plans can be decided. Alternative plans, too, where such suggest themselves, must be investigated with equal thoroughness for comparison and selection.

The flowage line of the San Francisco basins on the north side of the canal route should be completed, and the water sheds of the several streams measured. A new location should be made for the sea-level canal from Lock 1 eastward, avoiding the Benard Lagoon and cutting off a bend of the lower San Juanillo, in order to ascertain its comparative advantages with that of the present location. In other respects than the topography the company's data are insufficient. There have been no borings over a portion of the sea-level canal, and no explorations made of the depth and other difficulties to be apprehended in the endeavor to traverse the Benard Lagoon.

In the eastern divide the borings are 1,000 feet apart on the axis of the canal line only. The cores furnished by the diamond drills having been lost, the borings should be repeated at more frequent intervals, and additional borings made along the side lines of the canal for the better determination of the materials and what should be the proper slope to be given them. Wherever bad or doubtful material is found the borings should be multiplied to ascertain its limits, and samples of all materials should be carefully preserved, not only to verify the judgment of the engineer in local charge of the boring party, but for the later information of contractors who may be invited to submit proposals for the work. Some of the embankments in the San Francisco basins traverse mud bottoms of unknown depth. These should be fully explored for the preparation of construction plans and specifications. All streams, large and small, that may affect the construction and maintenance of the canal should be gauged and their volume and regimen determined as fundamental data by which to determine the levels and proportions of the work.

But aside from these particulars, which are essential to the proper estimation of the company's project, the entire matter of the choice of route for the eastern division should be reexamined. The cost of the most exhaustive surveys is small in comparison with that of an important error in location. The feasibility of the 1852 project of Colonel Childs for slack-water navigation of the San Juan has not been questioned for that portion of the river lying above the mouth of the San Carlos, but below that point it appears more doubtful on account of the sandy nature of the San Juan bed. This sand is of volcanic origin, and has been brought down in large quantities by the San Carlos from the volcanic range in Costa Rica, where that river has its sources. The original supply of sand has been intermittent in character and variable in amount, and for some time past has been suspended entirely. The indications are that the sand movement is small at the present time, and there is reason to believe that the period of volcanic activity in this region is past. Could this be made reasonably certain, the main objection to a slack-water navigation between the mouth of the San Carlos and the mouth of the Serapiqui would disappear and the project would present many advantages. Two or three dams of moderate lift would be required below the San Carlos, and the surveys for this purpose would include not only the sites for dams, but the stretches of river between them where excavation of the sand bed would be required to deepen the channel. It will also be necessary to make a thorough examination of the comparatively unexplored region lying south of the San Juan between the eastern ridge of the San Carlos and the eastern side of the Serapiqui.

In 1872 Commander Lull adopted the Childs plan with minor variations from the lake to the San Carlos River, and at this point his line left the river channel and continued down the left bank to near the San Juanillo. This route has been objected to as subject to overflow by floods in the San Juan and serious interference from the discharge of the San Francisco and other streams entering the San Juan within these limits, but as none of these rivers has been gauged to ascertain its regimen it is not known how serious this interference may be or if practical means can not be found to avoid it. The canal company has made a partial investigation of an alternative route below Ochoa, keeping at first farther from the river than Lull's line, but presently joining it. This location continued the use of the Ochoa Dam and the embankments of the San Carlos Ridge, but avoided the San Francisco embankments and the east divide cut. In view of the great cost of these constructions and the danger involved in the maintenance of great clay embankments subject to injury for military purposes or from malice, the alternative possibilities should be fully investigated prior to reaching a conclusion as to what route on the whole should be regarded as most expedient.

The examinations indicated will require for their satisfactory execution the employment of several well-equipped parties for a period of, say, eighteen months, in order to include at least two dry seasons, the amount of time required being affected by the fact that by reason of the constant rains, the heavy forest growth, and the topographical difficulties of the country less work can be accomplished in Nicaragua with the same time and the same force than in the United States.

In addition to the particulars above recited, observations of rainfall should be made over the entire route of the canal from Greytown to Brito, probably at the following points: Brito; the mouth of the Lajas, on the west side of the lake; Fort San Carlos, on the east side; at Toro Rapids, Castillo, Machuca, Ochoa, mouth of the San Francisco, Serapiqui, and on the east divide. The observations would cost little, as they could be made in connection with other work.

The examinations indicated are regarded as essential to the comprehension of those fundamental features of the problem which shall decide the final location and cost of the canal.

A preliminary estimate of the cost of the surveys, with a suitable staff and equipment of instruments, with boats and launches and a small river steamboat for facility of transportation, reaches the aggregate of $350,000 as the amount required.

CONCLUSIONS.

EASTERN DIVISION.

1. *Greytown Harbor.*—The entrance to the harbor as proposed by the company is too near the angle of the coast line, and, as is indicated on the accompanying map (Pl. XVIII), should be moved eastward about a mile and a half, the present lagoon to be used as the inner harbor and connected with the entrance by a canal with a bottom width of 200 feet. The harbor throughout should be dredged to 30 feet below low water, and its depth increased to 6 fathoms at the entrance.

2. *Canal, Greytown to Lock No. 1.*—A bottom width of 100 feet with a clear depth of 30 feet at low water, and two intermediate and one terminal siding for meeting of vessels, is preferable to the company's cross section of 120 feet bottom width, 28 feet depth, and no sidings.

The location of the canal through the Benard Lagoon is objectionable, and the line may probably be moved to the southward and straightened, with advantage.

3. *Lock No. 1 to end of summit level at Lock No. 3.*—To reduce the lift of locks and dams in the Deseado Valley, four locks of a maximum lift of 28 feet are preferable to three with maximum lift of 40 feet, as proposed by the company, particularly in view of the increase of the summit-level elevation from 106 to 110 feet above sea level. The company's cross section of the canal between locks has a bottom width of 120 feet. As indicated in paragraph 2, the Board believes that the width of 100 feet with sidings at proper intervals should be adopted.

4. *Eastern divide cut.*—Additional borings on the axis of the cut and parallel therewith, to cover proposed excavation, are necessary for information as to materials and their distribution. The vertical and $\frac{1}{5}$ to 1 slopes proposed by the company may have to be increased, and the cube thereby somewhat enlarged.

5. *San Francisco basins.*—The proposed basins between the east divide and the San Juan River at Ochoa involve long lines of heavy embankments in clay, traversing deep mud bottoms at some points, which will call for great care in construction. The width of the connecting channels now fixed by the company at 80 feet might be increased to 100 feet, to correspond with that of other sections, but this is not imperative. The height of all embankments should be raised to provide for a water-surface elevation of 110 or more instead of 106 as proposed by the company. Considering the large number of these embankments, the heavy rainfall to which they will be exposed, and the high head which many of them will sustain, the accumulated risk will be considerable and their maintenance will require special vigilance.

The Board deems it proper to make note of the facility with which a breach might be effected at any point of the long series of embankments employed in connection with the canal project, either for military purposes in time of war or at the prompting of a malicious intent.

LAKE AND RIVER DIVISION.

6. *Ochoa Dam.*—Thorough search should be made in the vicinity of the site now proposed for the Ochoa Dam for the most advantageous location of the structure, and the full nature of the foundations and the shore connections be exhaustively ascertained. As proposed by the company, the dam is to be a rock fill across a powerful river, on a sand foundation. A dam so constructed has no precedent, and its erection in conflict with the unknown volume of the floods presents grave difficulties. Its total dimensions and cost can not be reliably computed with the present data. A masonry structure would be preferable, if a suitable foundation could be discovered, and its cost not be prohibitory. It is believed that a rock-fill dam could be built after careful study of the physics of the river and the geology of the site; but, in order to do this, and, later, provide for a due regulation of the water level, it may be expedient to build sufficient sluices in the San Carlos Ridge to relieve the dam while under construction. The use of the dam as a weir is regarded as inadmissible, and its height must be such as to enable the surface level to be maintained at an elevation of 112 feet above the sea, or possibly higher.

7. *San Carlos Ridge.*—If sluices are not constructed in the ridge capable of diverting the full volume of the river in flood, weirs in suitable positions on the crest line will be necessary, and an elaborate system

of movable dams should be provided, the object being to maintain the lake summit level elevation at not less than 110 feet during the dry season and to limit its use during the rainy season to such height as may be necessary to avoid excessive damages for submergence of lands.

8. *San Juan River, Ochoa to lake.*—The river should be thoroughly surveyed and leveled throughout, and observations made for at least a calendar year to determine its varying slopes, volume, surface elevation, and regimen. Full explorations should be made of the river bed by borings or other suitable means to determine the materials to be excavated, both for channel improvement and to cut off bends for reduction of curvature. The channel should have a bottom width of not less than 250 feet, enlarged to 300 or 400 feet in bends, in lieu of 125 feet, and the deepening should be to 30 feet, instead of 28 feet as proposed by the company.

9. *Lake Nicaragua.*—The area and regimen of the lake should be determined and the extent and approximate value of the lands that would be overflowed at elevations 110 and 115 ascertained. The 14 miles of excavated channel on the east side should have a bottom width of not less than 300 feet, instead of 150 as proposed.

WESTERN DIVISION, LAKE TO BRITO.

10. The Lajas-Rio Grande route, adopted by the company, to connect the lake with the Pacific, is preferable to any other that has been examined. The information with reference to the site of the proposed La Flor Dam indicates that its construction is impracticable, and an alternative low-level route, which offers no special difficulties in construction, avoids any necessity for it. This alternative line may follow either the right or left bank in the Rio Grande Valley from a point 9.2 miles distant from the lake, which would constitute the western limit of the summit level. The northern or right-bank route has been located by the company. The southern or left-bank route should be fully located and bored to determine its relative merit. It has the advantage of avoiding complication with the discharge from the Tola watershed and the cost of diverting the Upper Rio Grande, and the disadvantage of requiring more diversions of the Rio Grande in the main valley.

11. *Brito Harbor.*—The exposure to the full force of the Pacific seas in the deep water close at hand calls for protecting works of adequate magnitude and power of resistance. A large extension of the breakwater is required for the protection of the entrance, and the borings and other considerations indicate the desirability of moving it southeastward from the location proposed by the company. The site should be fully explored with reference to the subsurface materials.

GENERAL.

12. All locks should have a width of not less than 80 feet if the navigation be intended to provide for the passage of war vessels and for future developments in the case of commercial vessels. The U. S. S. *Iowa* and others of the same class have a beam of 72 feet 3 inches, and still others are now contemplated with a beam of 75 feet.

13. All streams affecting the canal route should be gauged to ascertain their regimen, and in particular the regimen of the lake and the San Juan and San Carlos rivers should be carefully determined.

14. Rainfall observations should be made at several consecutive points over the entire route from Greytown to Brito.

15. The construction of the eastern division on the line proposed by the company is feasible, but in view of the risks involved in the maintenance of the numerous dams and embankments the final adoption of any route is inexpedient until all alternative routes shall have been fully investigated and compared.

16. Full explorations for alternative routes in the eastern division should include the so-called low-level line on the left bank of the San Juan to the San Juanillo and thence to Greytown; and, more particularly, full investigation should be made as to the practicability of extending the canalization of the river to the vicinity of the Serapiqui by means of comparatively low dams.

17. The cost of work, particularly in the eastern division, will be increased in consequence of the heavy rainfall, but from observations made, its destructive effect on completed work will be much less than that of frost in the United States.

18. The climate of Nicaragua is mild, equable, and humid, and while the sanitary conditions are not unfavorable as compared with portions of the United States, the value of physical labor is much less. It is probably to be expected that the opening of earth excavations will be attended, as elsewhere, by the development of malarial diseases, but not of a specially malignant type.

19. The volcanic and seismic forces in Nicaragua are manifestly declining, and there seems little reason to apprehend disturbance of so serious a character as to imperil the stability of canal construction.

20. The official estimate by the company of $66,466,880 is insufficient for the work. In several important cases the quantities must be greatly increased, and in numerous cases the unit prices do not make proper allowance for the difference in cost of work between the United States and Nicaragua.

21. The provisional estimate by the Board is $133,472,893. It should be understood that the existing data are inadequate as a basis for estimating the cost of many of the structures; some portions of the work may cost more, others less, but in the judgment of the Board the entire project can be executed for about the total amount of its estimate.

22. For obtaining the necessary data for the formation of a final project, eighteen months' time, covering two dry seasons and an expenditure of $350,000, will be required.

William Ludlow,
Lieutenant-Colonel, Corps of Engineers, U. S. A.
Mordecai T. Endicott,
Civil Engineer, U. S. N.
Alfred Noble,
Civil Engineer.

COST OF WORK AND ESTIMATES.

CLIMATIC AND LABOR CONDITIONS.

Before fixing unit prices for an estimate of cost of the canal, the Board has examined with much care a large amount of data relating to cost of similar work in the United States. Several contractors of high reputation in their respective lines have examined the maps and plans, and have aided the Board by furnishing estimates of cost of various classes of work. Several gentlemen of wide experience in the execution of work in the Tropics have also given information of great value.

It can not be expected that work can be done in Nicaragua at prices ruling in the United States. The first cause of this, which will readily appear to anyone, is the climate. There is a great difference in this respect between the two coasts.

On the Atlantic coast, at Greytown, it rains nearly every day in the year. The annual rainfall is five or six times as much as on the Atlantic coast of the United States. Very heavy rains occur at times; on one occasion there was a rainfall of 35 inches in eight days, with a maximum of 5.8 inches in twenty-four hours. At another time a fall of 9 inches in nine hours was noted. The range of temperature is small; it seldom rises to 90° or falls to 70°. Notwithstanding the moderate temperature, the heat becomes very oppressive when physical exertion is made, on account of the high humidity. Substantially the same conditions as to rainfall and humidity appear to prevail over the entire eastern division.

The heavy rainfall will increase largely the cost of excavating the deep mud at several embankment sites; of clay excavation; of building the embankments, where it may prove difficult to solidify the material properly on account of the presence of too much water; of concrete for the locks, sluices, and weirs, for which it may be necessary to provide temporary shelter; and, to a less extent, the cost of rock excavation and other work.

West of the mouth of the San Carlos the rainfall diminishes, and in the lake basin there is a well-defined dry season. At Rivas, 5 miles north of the canal line, between the lake and the Pacific, a rainfall record has been kept by Dr. Earl Flint, an American resident, since 1880; the greatest annual rainfall in this period was 105 inches; the least 32 inches, and the mean 65 inches; at this point, where the conditions along the western division are fairly represented, the dry season continues about five months. The temperature rises a little higher than at Greytown, but the humidity is less, and, on the whole, the climatic conditions are much more favorable.

Another cause for higher cost of work in Central America is the comparatively ineffective manual labor which has to be relied upon. The natives of Nicaragua are not likely to prove useful laborers in the severe and steady work of canal construction. Negroes from the West Indies, principally from Jamaica, have been employed largely at Panama and on the Costa Rica Railway. Under good management they are docile and from a tropical standpoint are considered industrious and fairly effective. They will undoubtedly form the labor supply for the canal. Wages are only about one-half as much as in the United States, but the efficiency of the laborers is much less in proportion.

There is a marked concurrence in opinion of those who have had experience in the management of construction work in Central America that the cost of work, due to inefficient labor and unfavorable location and climate, is about twice as much as in the United States.

Machinery will be used largely, but will be of little value after completion of the canal, and hardly any of it will be worth removal; its entire cost would, therefore, be charged to canal construction, making the plant charge higher than usual. Repairs of plant will be expensive. There are now no shops or facilities of any kind on or near the canal line, and they will have to be supplied as adjuncts of the work.

There is no skilled labor in the country, and it will have to be imported at rates of wages much higher than prevail here. Extra men will have to be kept on hand, transportation to and from the United States will have to be paid, and it may be said that the expenditure on account of pay rolls and traveling expenses will be twice as much as in the United States. Fuel will cost more than double. Freight on materials and supplies will increase their cost greatly, particularly if sent to interior points.

It appears therefore that the rule applied to manual labor will hold good also as to work done by machinery, and in general the cost will be doubled. On the Atlantic Coast, the factor should be somewhat greater than two; on the Pacific Coast, somewhat less.

So far as shown by experience, the sanitary conditions in Nicaragua are favorable. During the building of the railroad across the swamps from Greytown westward the health record of the men, who were mostly Jamaica negroes, was very good, although they were constantly in the water.

When deep excavations are made in the clay there may be a different result. The Jamaicans, however, suffered little when employed in the construction of the Costa Rica Railroad, where the cuts through the hills were very heavy, and it is believed that with these or other acclimated laborers, under complete police control and subjected to judicious sanitary regulations, there will be no more sickness than occurs on public works in many parts of the United States.

UNIT PRICES.

DREDGING.

Greytown Harbor.—Material, coarse volcanic sand of light specific gravity. It will have to be deposited outside the harbor lines, either in the swamps or at sea. There will be some exposure to the sea in the harbor entrance. The interior dredging can be done for 20 cents; in the entrance, 40 cents; average price used in the estimate for the entire amount, 25 cents per cubic yard.

Greytown Harbor to Lock No. 1.—Material, sand for one-third of the distance; then mud and clay. From the west end the tow will be long, if material is taken to sea; if deposited on bank by a pump or ejector the lift will be about 20 feet, plus height of spoil bank. Estimate price, 25 cents per cubic yard.

San Juan River.—Material, according to Lull's classification, made from lead-line indications, is clay, sand, and gravel. A large amount of material classified by him as rock is believed to be gravel and bowlders and is so taken in the estimates. A large part of the material will have to be delivered on river bank to avoid reducing channel area. On account of this, and the uncertainty as to the nature of the material, the unit price in the estimate is increased to 30 cents per cubic yard.

Lake Nicaragua.—Material, mud and clay. The quantity is large and the situation sheltered. The clay can be dumped within a short distance; the mud can be pumped to a sufficient distance to insure against running back into the cut. Estimate price, 20 cents per cubic yard.

Brito Harbor.—Material and conditions similar to those at Greytown Harbor, and same unit price used—25 cents per cubic yard.

EARTH EXCAVATION.

Eastern division.—Material, stiff clay. At the Chicago drainage canal, excavation of hard clay with steam shovel costs 22 to 25 cents per cubic yard where the ground is level and plant for dumping can be moved easily; the work there is done in the main when the ground is dry. In the heavy rainfall region of eastern Nicaragua the material will become difficult to handle; the lock pits will be deep and will require some pumping; the canal line between locks is crossed several times by the Deseado, which will have to be diverted, and cost charged to excavation. In the east divide and beyond to Ochoa the country is made up of steep hills, where it will be difficult to work plant to advantage. Estimate price, 60 cents per cubic yard.

San Carlos embankment line.—Material, clay. Excavation is made to remove surface soil at sites of embankments; therefore of small depth, usually of small area; material to be dumped just outside of excavation. Estimate price, 50 cents per cubic yard.

San Juan River.—Material, probably clay. Excavation required to straighten channel. Rainfall becomes less going west. Estimate price, 50 cents per cubic yard.

Western division.—Material, light loam, sand, and clay. Rainfall less, and country less hilly. Estimate price, 40 cents per cubic yard.

ROCK EXCAVATION.

Eastern division.—Material all degrees of hardness from telpetate to trap; of volcanic origin and not stratified. The harder rock will not drill and blast nearly as well as the rock in the Chicago Drainage Canal, where the contract price is about 70 cents. It will not drill or break better than the gneiss about New York City, which costs for excavation about 80 cents. The telpetate is softer, but it may prove impossible to maintain it vertical or with slope of 1:5, as proposed by the company. The country is a mass of hills, and plant can not be handled as readily or employed as usefully as in a level district. The heavy rainfall will increase cost of work. Estimate price, $1.75 per cubic yard.

Western division.—Material, similar to that in eastern division, but with less hilly ground and better climate; the Board assumes the unit price at $1.25 per cubic yard.

MUD EXCAVATION.

Eastern division.—East of divide small quantities of moderate depth are to be removed from embankment sites; estimate price, $1 per cubic yard. West of divide at sites of several embankments mud is to be excavated to depth of 30 feet or more. Cost of protecting sides of cut by crib work or other means to prevent slides into cut will be large, and is included in the estimate price of $1.50 per cubic yard.

EMBANKMENT.

Greytown Harbor to east divide.—Material, clay. To be placed on cars when excavated from lock or canal prism. Embankment price covers cost of transportation, taking from cars, placing in embankment, and rolling or tamping. Company's price used in estimate, 30 cents per cubic yard.

East divide to Ochoa.—Material, clay. About half will have to be borrowed. Estimate price, 45 cents per cubic yard, which allows 30 cents for excavating one-half of the material from pits favorably located.

San Carlos ridge line.—Material, clay. All will have to be borrowed. Embankments are generally small, at considerable distance apart. An excavation price of 40 cents is added to an embankment price of 30 cents, making the price used in the estimate 70 cents per cubic yard.

BACK FILLING BEHIND LOCK WALLS.

Eastern division.—Material, clay. In most cases to be excavated from side of lock pit to lighten bank. Locks generally located in hills. If quantity is insufficient, deficiency is to be made up by borrowing. Excavation price of 40 cents added to embankment price of 30 cents, making 70 cents per cubic yard.

Western division.—On account of material being more easily handled and more favorable climate the price is reduced in the estimate to 60 cents per cubic yard.

MATERIALS FOR OCHOA DAM.

Rock fill.—Material to be principally in pieces weighing 4 to 10 tons, obtained from east divide. A sufficient amount can not be obtained by ordinary blasting, therefore quarry methods will be required, adding to cost of excavation.

	Per cubic yard.
Additional cost of excavation is estimated at	$0.50
Transportation to dam (1 cent per ton mile)	.30
Handling at dam	.20
A large amount will have to be stored for final season's work, involving two handlings; cost of this distributed over whole amount	.15
Cost per cubic yard, solid	1.15

One cubic yard solid makes 1.7 cubic yards loose. Cost of 1 cubic yard loose, 68 cents, say, 70 cents for estimate price.

Earth fill.—Material, small stone and clay. Waste from east divide:

	Per cubic yard.
Transportation	$0.30
Handling at dam	.20
Estimate price	.50

SUBMARINE ROCK EXCAVATION.

San Juan at Toro and Castillo rapids and at canal entrance west side of lake.—Material, probably hard, volcanic rock, without stratification except on west side of lake; latter amount relatively small. Work will be done with expensive plant and skilled labor; plant should be charged to work. Present contract price for limestone, hard but horizontally stratified, drilling and blasting well, in the St. Marys River, Michigan, $2.43 per cubic yard. In Nicaragua cost of plant will be 50 per cent greater, pay roll will be double, cost of repairs and fuel more than double. Estimate price, $5.

SHEET PILING.

The unit prices in the company's estimate, which provide for creosoted timber, are accepted by the Board.

STONE FOR BREAKWATERS.

Greytown and Brito.—Stone from divide cuts. Stone to be received on cars at points where excavated. Cost of transporting and depositing in breakwaters, including necessary trestle, will not, it is believed, exceed the estimate price of $1.50 per cubic yard. The trestle will be a temporary pile bridge; storms seldom occur, and cost of trestle will not be great.

CONCRETE FOR LOCKS, SLUICES, AND WEIRS.

Eastern divison.—Greater part of work from 12 to 17 miles from Caribbean; a few small works 22 to 28 miles; cement, Portland, delivered by ship at Greytown; sand from Greytown beach; stone from east divide cut. Proportions suggested by company: Cement, 1; sand, 2; stone, 5 by volume. Concrete for lock construction with these proportions costs $9 per cubic yard, including timber forms, at the Hennepin Canal, 1893. With proportions of 1:2:3 for face and 1:3:6 for backing, the cost can be reduced and satisfactory structures obtained.

A careful, detailed estimate has been made and $9.50 adopted as the estimate price.

San Carlos sluices and weirs.—Transportation of materials to site will be more expensive than for eastern division, and the estimate price is made $10.

Western division.—Cement will cost a little more than on the eastern division, by reason of higher freight charges. Cost of sand from the beach at Brito and stone from the west divide will be less than sand and stone in eastern division, on account of better climate; cost of mixing and placing will be less; these reductions will more than offset the greater cost of cement. Estimate price, $9 per cubic yard.

METAL WORK.

Lock gates.—The contract price for the steel gates just built for the St. Marys Falls Canal was 7 cents per pound. Material will probably come from Europe at less than first cost in the United States. Erection in Nicaragua will cost more than here, and the final cost is taken the same as here, at 7 cents per pound.

Gate anchors.—Contract price at St. Marys Falls Canal is 3.77 cents per pound; estimate price, 4 cents per pound.

Steel in foundations.—Material to come from Europe. Field riveting small in amount. Estimate price, 3 cents per pound.

Steel in culverts.—Material from Europe. Field riveting and calking expensive in Nicaragua. Price for estimate, 4 cents per pound.

Gates and machinery for sluices.—The prices taken by the Board are makers' prices, with an allowance for transportation. The company's estimate appears to be made for only one-half the number of gates intended.

SLUICES AND WEIRS.

Eastern division.—The company's estimate provides two sluice openings 20 feet by 25 feet and 200 linear feet of weir at each lock, and equal amounts of both in the San Francisco embankment line. For the purpose of entering the items in the estimate the Board assumes the same provision.

San Carlos embankment line.—The price estimated provides for 4,000 feet linear of weir instead of 1,200 feet, as in the company's estimate. No change is made in the number of sluices. These quantities, which may have to be changed after further surveys, are assumed only to take the items into account.

RAILROADS.

Eastern division.—The estimate of $100,000 per mile is believed sufficient for a double-track standard-gauge railroad. The country is hilly, the grading will be heavy, and there will be considerable pile bridging and trestling; but there will probably be no rock cuts. The amounts added for buildings, etc., are sufficient for the temporary buildings suitable for a construction line.

Western division.—With a low-level canal there will be no difficulty locating a railroad with light work and easy grades and curves, excepting the 1½ miles through the gorge of the Rio Grande. Estimate price, $50,000 per mile for a double-track standard-gauge railroad.

MISCELLANEOUS.

The Board has adopted the company's figures in many cases for minor structures, and in a few cases for important ones, where it was impossible to check them with the limited time and means at its disposal. The most important of these structures are the weirs and guard gates. As to the weirs, their dimensions are subject to change after the ascertainment of the duty required of them, and changes in their dimensions, if in the way of increase, must at this stage be considered as an item of contingencies. As to the guard gates there are no plans, but the amount estimated for them by the company may possibly prove sufficient.

The company's estimate contains amounts for receiving basins for several creeks taken into the canal, for fender work in the approaches to the locks, and for a few other small items. The Board has entered the amounts in its estimates without analyzing them minutely; any errors in amount will be relatively unimportant.

In the absence of any data on the subject the Board has not endeavored to make any estimate as to the damages to be incurred from submergence of lands in lake and river valleys.

MANAGEMENT AND ENGINEERING.

Cost of management and engineering is estimated at 4 per cent of the cost of construction.

HOSPITAL SERVICE.

Adequate hospital service is of prime importance for the successful prosecution of the work. It would not be judicious to leave this to the control of the large number of contractors who would be employed, as they would not be likely to agree on effective measures, and lack of vigilance at any point might start a disastrous epidemic. For these reasons the canal company should assume the responsibility, and organize a hospital service on a liberal scale. An item of $1,000,000 is inserted in the estimate for this purpose.

CONTINGENCIES.

The allowance for contingencies is intended to cover those items of increase due to unforeseen emergencies and exigencies as to climate and imperfect information as to the extent and character of the work; in the present case, these uncertainties are unusually large, and in the judgment of the Board the allowance of 20 per cent is the least admissible.

QUANTITIES.

The quantities of excavation and embankment carried in the estimate are based on the company's maps and profiles, and in most cases, unless otherwise stated in the report, its calculations of amounts are accepted The Board has verified them approximately, and believes the maps and profiles on which they are based to be substantially correct.

Estimate.

EASTERN DIVISION.

[From Greytown Harbor to San Juan River.]

	Company's estimate, 1895.			Board's estimate, 1895.		
	Quantity.	Unit price.	Cost.	Quantity.	Unit price.	Cost.
GREYTOWN HARBOR.						
Pile pier .... linear feet..	900		$190,215.00	1,500		*a* $105,000.00
Piers of loose rock .... do....	1,200					
Rock .... cubic yards..	286,095	$1.50	429,143.00	530,000	$1.50	795,000.00
Piers at entrance to canal			100,000.00			
Dredging .... cubic yards..	9,550,000	.15	1,432,500.00	12,000,000	.25	3,000,000.00
Stone pitching, channel banks .... do....				150,000	2.00	300,000.00
Railroad and trestle, single track .... miles..				3	50,000.00	150,000.00
Wharves						100,000.00
Machine shop						20,000.00
Warehouse						10,000.00
Total Greytown Harbor			2,151,858.00			4,480,000.00
GREYTOWN HARBOR TO EAST DIVIDE.						
Clearing and grubbing for canal .... acres..	925	100.00	92,500.00	925	100.00	*b* 92,500.00
Clearing and grubbing for embankments .... do....	24	100.00	2,400.00	24	100.00	*b* 2,400.00
Clearing only for embankments .... do....	25	50.00	1,250.00	25	50.00	*b* 1,250.00
Dredging for canal .... cubic yards..	13,547,597	.15	2,032,139.00	14,306,000	.25	3,576,500.00
Dredging, diversions of lower Deseado .... do....	105,500	.20	21,100.00	172,500	.25	43,125.00
Earth excavation for canal, clay .... do....	2,396,225	.40	958,490.00	2,412,008	.60	1,447,204.80
Earth excavation for locks, clay .... do....	1,301,194	.40	520,477.00	2,151,005	.60	1,290,603.00
Earth excavation at sites of embankments, clay .... do....	55,105	.40	22,042.00	47,326	.60	28,395.60
Earth excavation at sites of embankments, mud .... do....	11,233	1.00	11,233.00	9,470	1.00	9,470.00
Earth excavation at sites of sluices, clay .... do....	191,508	.40	76,603.00	331,508	.60	198,904.80
Earth excavation at sites of sluices, mud .... do....	4,148	1.00	4,148.00	4,148	1.00	4,148.00
Earth embankments .... do....	469,464	.30	140,839.00	433,191	.30	129,957.30
Stone pitching, sides of canal .... do....	172,288	2.00	344,576.00	172,288	2.00	*b* 344,576.00
Stone pitching on embankments .... square yards..	53,500	2.00	107,000.00	44,223	2.00	88,446.00
Sheet piling for embankments .... feet, B. M..	1,424,000	.07	99,680.00	1,760,000	.07	123,200.00
Wales, ties, etc., for sheet piling .... do....	250,000	.06	15,000.00	280,000	.06	16,800.00
Weirs .... linear feet..	1,200		823,462.00	1,600		431,283.00
Locks: *c*						
Sheet piling .... feet, B. M..				5,400,000	.07	378,000.00
Concrete .... cubic yards..	388,101	6.00	2,328,606.00	507,031	9.50	4,816,794.50
Granite quoins .... do....				3,550	60.00	213,000.00
Steel in foundations .... pounds..				11,520,000	.03	345,600.00
Steel in culverts .... do....				4,112,000	.04	164,480.00

Gates ... do			418,800.00	7,632,000	.07	534,240.00
Gate anchors ... do				1,200,000	.04	48,000.00
Machinery			800,000.00			450,000.00
Buildings			90,000.00			150,000.00
Pumping at Lock No. 1			100,000.00			
Stone pitching in basin ... cubic yards	4,800	2.00	9,600.00	4,800	2.00	*b* 9,600.00
Fender piles at Locks Nos. 1 and 2 ... number	2,040	13.50	27,540.00	2,040	13.50	*b* 27,540.00
Fender wales at Locks Nos. 1 and 2 ... cubic feet	7,398	.50	3,699.00	7,398	.50	*b* 3,699.00
Fender cribs for Lock No. 3 ... number	32	500.00	16,000.00	32	500.00	*b* 16,000.00
Back filling at locks ... cubic yards				600,000	.70	420,000.00
Sluices, each 2 openings, 20 by 25 feet ... number	3			4		
Sheet piling ... feet, B. M	1,126,400	.07	78,848.00	1,232,000	.07	86,240.00
Wales, ties, etc ... do	176,000	.06	10,560.00	200,000	.06	12,000.00
Concrete ... cubic yards	74,256	6.00	445,536.00	94,338	9.50	896,211.00
Gates and machinery			75,000.00			240,000.00
Railroad, single track ... miles	19	50,000.00	950,000.00	19	50,000.00	950,000.00
Sidings ... do				3	10,000.00	30,000.00
Stations, shops, tanks, etc						56,000.00
Telegraph ... miles	19	500.00	9,500.00	19	500.00	*b* 9,500.00
Total Greytown Harbor to east divide			9,636,137.00			17,685,668.00
EAST DIVIDE.						
Clearing and grubbing ... acres	169	100.00	16,900.00	169	100.00	*b* 16,900.00
Earth excavation ... cubic yards	3,387,396	.40	1,354,958.00	3,387,396	.60	2,032,437.60
Rock excavation ... do	8,310,084	1.25	10,387,605.00	8,310,084	1.75	14,542,647.00
Railroad, single track ... miles	3	50,000.00	150,000.00			
Railroad, double track ... do				3	100,000.00	300,000.00
Sidings ... do				3	10,000.00	30,000.00
Stations, tank, etc						17,000.00
Telegraph ... miles	3	500.00	1,500.00	3	500.00	*b* 1,500.00
Total east divide			11,910,963.00			16,940,484.00
EAST DIVIDE TO OCHOA.						
Clearing and grubbing for canal ... acres	725	100.00	72,500.00	725	100.00	*b* 72,500.00
Clearing and grubbing for embankments, weirs, and sluices ... do	158	100.00	15,800.00	158	100.00	*b* 15,800.00
Clearing only, for embankments, weirs, and sluices ... do	104	50.00	5,200.00	104	50.00	*b* 5,200.00
Earth excavation for canal, clay ... cubic yards	2,698,195	.40	1,079,278.00	2,698,195	.60	1,618,917.00
Earth excavation at sites of embankments ... do	450,843	.40	180,337.00	585,874	.60	351,524.40
Earth excavation at sites of embankments, mud ... do	1,051,816	1.00	1,051,816.00	1,092,978	1.50	1,639,467.00
Earth excavation for sluices, clay ... do	529,650	.40	211,860.00	529,650	.60	317,790.00
Rock excavation for canal ... do	30,309	1.50	45,463.00	30,309	1.75	53,040.75
Earth embankments ... do	6,075,221	.30	1,822,566.00	7,166,060	.45	3,224,727.00
Sheet piling for embankments ... feet, B. M	4,032,000	.07	282,240.00	4,032,000	.07	282,240.00
Wales, ties, etc ... do	524,000	.06	31,440.00	524,000	.06	31,440.00
Stone pitching on embankments ... square yards	426,900	2.00	853,800.00	557,969	2.00	1,115,938.00

a 1,500 linear feet pile bridge at $40, $60,000; 15,000 cubic yards loose rock at $3, $45,000. *b* Company's estimate assumed.

c In company's estimate, 3 locks, with lifts of 31, 35 and 40 feet from sea to summit level, at elevation 106. In Board's estimate, 4 locks, with lifts of 26, 28, 28, and 28 feet from sea to summit level, at elevation 110.

Estimate—Continued.

EASTERN DIVISION—Continued.

[From Greytown Harbor to San Juan River.]

	Company's estimate, 1895.			Board's estimate, 1895.		
	Quantity.	Unit price.	Cost.	Quantity.	Unit price.	Cost.
EAST DIVIDE TO OCHOA—continued.						
Concrete dam ... cubic yards	1,129	$6.00	$6,774.00	2,255	$9.50	$21,422.50
3 weirs, 200 feet each ... linear feet	600		208,510.00	600		*a*208,510.00
3 sluices, each 2 openings, 20 by 25 feet:						
Sheet piling ... feet, B. M.	1,065,600	.07	74,592.00	1,165,000	.07	81,550.00
Wales, ties, etc ... do.	166,000	.06	9,960.00	180,000	.06	10,800.00
Concrete ... cubic yards	100,625	6.00	603,750.00	107,187	9.50	1,018,276.50
Gates and machinery			75,000.00			180,000.00
Guard gates between Machuca and Danta			800,000.00			300,000.00
Railroad, single track ... miles	15	50,000.00	750,000.00			
Railroad, double track ... do.				15	100,000.00	1,500,000.00
Sidings ... do.				9	10,000.00	90,000.00
Stations, tank, etc						41,000.00
Telegraph (divide to Castillo) ... miles	40	500.00	20,000.00	40	500.00	20,000.00
Total east divide to Ochoa			7,700,886.00			12,200,143.15
RECAPITULATION, EASTERN DIVISION.						
Greytown Harbor			2,151,858.00			4,480,000.00
Greytown Harbor to east divide			9,636,137.00			17,685,668.00
East divide			11,910,963.00			16,940,484.00
East divide to Ochoa			7,700,886.00			12,200,143.00
Total eastern division			31,399,844.00			51,306,295.00

THE LAKE AND RIVER DIVISION.

[From Ochoa to the west side of Lake Nicaragua.]

OCHOA DAM.						
Earth excavation for abutments ... cubic yards	18,500	$1.00	$18,500.00			
Sheet piling for abutments ... feet, B. M.	800,000	.075	60,000.00			
Wales, ties, etc ... do.	100,000	.06	6,000.00			
Concrete for abutments ... cubic yards	1,550	10.00	15,500.00			
Rock fill for dam ... do.	1,200,000	.50	600,000.00	2,000,000	$0.70	$1,400,000.00

Earth fill for dam ... do.	629,000	.25	157,273.00	600,000	.50	300,000.00
Cable conveyors ... number.	3	40,000.00	120,000.00	10	15,000.00	150,000.00
Abutments						550,000.00
Sheet piling under earth fill						100,000.00
Diversion of San Juan (sluices, etc.)						1,500,000.00
Total Ochoa Dam			977,273.00			4,000,000.00
SAN CARLOS EMBANKMENT LINE.						
Clearing and grubbing ... acres.	15	100.00	1,500.00	15	100.00	*a* 1,500.00
Clearing only ... do.	22	50.00	1,100.00	22	50.00	*a* 1,100.00
Earth excavation at sites of embankment ... cubic yards.	31,092	.50	15,546.00	49,362	.50	24,681.00
Earth excavation for sluices ... do.	25,367	.50	12,684.00	25,367	.50	12,683.50
Earth embankments ... do.	195,131	.40	78,052.00	275,229	.70	192,660.30
Stone pitching on embankments ... square yards.	32,128	3.00	96,384.00	47,391	3.00	142,173.00
Weirs ... linear feet.	1,200		414,540.00	4,000	600.00	2,400,000.00
2 sluices, each 2 openings, 20 by 25 feet:						
Sheet piling ... feet, B. M.	800,000	.07	56,000.00	925,000	.07	64,750.00
Wales, ties, etc. ... do.	125,000	.06	7,500.00	135,000	.06	8,100.00
Concrete ... cubic yards.	44,517	6.00	267,102.00	49,277	10.00	492,770.00
Gates and machinery			50,000.00			120,000.00
Total San Carlos embankment line			1,000,408.00			3,460,417.80
SAN JUAN RIVER.						
Clearing and grubbing ... acres.	377	100.00	37,700.00	377	100.00	*a* 37,700.00
Earth excavation above water ... cubic yards.	422,540	.40	169,416.00	1,500,000	.50	750,000.00
Dredging ... do.	2,150,900	.25	537,725.00	10,163,000	.30	3,048,900.00
Rock excavation under water ... do.	398,613	3.00	1,195,839.00	2,199,000	5.00	10,995,000.00
Telegraph line ... miles.	70	500.00	35,000.00	70	500.00	*a* 35,000.00
Total San Juan River			1,975,280.00			14,866,600.00
LAKE NICARAGUA.						
Dredging, east side of lake ... cubic yards.	4,726,076	.20	945,215.00	12,300,000	.20	2,460,000.00
Rock excavation under water, west side of lake ... do.	176,832	3.00	530,496.00	190,723	5.00	953,615.00
Piers at entrance to canal, western division			493,710.00			*a* 493,710.00
Total Lake Nicaragua			1,969,421.00			3,907,325.00
RECAPITULATION, LAKE AND RIVER DIVISION.						
Ochoa Dam			977,273.00			4,000,000.00
San Carlos embankment line			1,000,408.00			3,460,418.00
San Juan River			1,975,680.00			14,866,600.00
Lake Nicaragua			1,969,421.00			3,907,325.00
Total lake and river division			5,922,782.00			26,234,343.00

a Company's estimate assumed.

Estimate—Continued.

WESTERN DIVISION.

[From Lake Nicaragua to the Pacific Ocean.]

	Company's estimate, 1895.			Board's estimate, 1895.		
	Quantity.	Unit price.	Cost.	Quantity.	Unit price.	Cost.
LAKE NICARAGUA TO TIDE LOCK AT BRITO.						
Tola Basin line—						
Clearing and grubbing for canal ... acres	1,033	$50.00	$51,650.00			
Clearing and grubbing for La Flor Dam ... do	17	50.00	850.00			
Earth excavation for canal ... cubic yards	5,594,809	.35	1,958,183.00			
Earth excavation for locks ... do	324,800	.40	129,920.00			
Earth excavation for La Flor Dam ... do	320,000	.40	128,000.00			
Earth excavation for diversion of Lajas ... do	299,508	.40	119,803.00			
Rock excavation for canal ... do	6,597,517	1.00	6,597,517.00			
Rock excavation for Locks Nos. 4 and 5 ... do	664,194	1.00	664,194.00			
Rock excavation for Lock No. 6 ... do	61,698	1.25	77,122.00			
Rock excavation for diversion of Lajas ... do	164,786	1.25	205,983.00			
Stone pitching sides of canal ... do	20,753	2.00	41,506.00			
Earth embankment at head of Lock No. 4 ... do	189,016	.50	94,508.00			
La Flor Dam:						
Sheet piling ... feet B. M.	796,800	.075	59,760.00			
Wales, ties, etc ... do	50,000	.05	2,500.00			
Piles for trestles ... number	322	5.00	1,610.00			
Trestle for dumping materials ... linear feet	1,600	22.00	35,200.00			
Concrete in core wall ... cubic yards	86,000	6.00	516,000.00			
Rock fill for dam ... do	830,000	.50	415,000.00			
Earth fill for dam ... do	918,000	.20	183,600.00			
Weir ... linear feet	250		93,000.00			
Locks: *a*						
Concrete ... cubic yards	376,000	6.00	2,256,000.00			
Gates			364,935.00			
Machinery			200,000.00			
Buildings			75,000.00			
Pumping at Lock No. 6			100,000.00			
Foundation for Lock No. 6			250,000.00			
Fender piles ... number	2,040	13.50	27,540.00			
Fender wales ... cubic feet	7,397	.50	3,699.00			
Stone pitching in basins ... cubic yards	4,800	2.00	9,600.00			
Masonry wall at head of Lock No. 4 ... do	19,080	10.00	190,800.00			
Guard gates in west divide cut			300,000.00			
Right of way			100,000.00			
3 drawbridges			60,000.00			

Railroad, single track, narrow gauge	miles	18	25,000.00	450,000.00			
Telegraph	do	18	500.00	9,000.00			
Total Lake Nicaragua to tide lock at Brito, via Tola Basin line				15,772,480.00			
Low level line:							
Clearing and grubbing for canal	acres	1,033	50.00	51,650.00	1,033	$100.00	$103,300.00
Earth excavation for canal	cubic yards	9,864,730	.35	3,452,655.00	10,025,000	.40	4,010,000.00
Earth excavation for Locks Nos. 4, 5, and 6	do	340,828	.35	119,290.00	1,489,000	.40	595,600.00
Earth excavation for Lock No. 7	do	124,800	.40	49,920.00			
Earth excavation for weir and dam	do				94,000	.40	37,600.00
Earth excavation for diversion of Lajas	do	299,508	.40	119,803.00	299.508	.40	b119,803.20
Earth excavation for diversion of lower Rio Grande	do	643,392	.35	225,187.00	1,370,000	.40	548,000.00
Earth excavation for diversion of Upper Rio Grande	do	1,592,435	.35	557,852.00			
Rock excavation for canal	do	7,179,949	1.00	7,179,949.00	7,179,949	1.25	8,974,936.25
Rock excavation for Locks Nos. 4, 5, and 6	do	569,422	1.00	569,422.00	207,000	1.25	258,750.00
Rock excavation for Lock No. 7	do	61,698	1.25	77,122.00			
Rock excavation for weir and dam	do				42,000	1.25	52,500.00
Rock excavation for diversion of Lajas	do	164,786	1.25	205,983.00	164,786	1.25	b205,982.50
Rock excavation for diversion of Upper Rio Grande	do	403,649	1.00	403,649.00			
Stone pitching sides of canal	do	62,370	2.00	124,740.00	62,370	2.00	b124,740.00
Locks c—							
Sheet piling	feet, B. M				2,700,000	.07	d189,000.00
Concrete	cubic yards	486,132	6.00	2,916,792.00	506,056	9.00	4,554,504.00
Granite quoins	do				3,600	60.00	216,000.00
Steel in foundations	pounds				11,520,000	.03	345,600.00
Steel in culverts	do				4,112,000	.04	164,480.00
Gates	do			459,738.00	8,000,000	.07	560,000.00
Gate anchors	do				1,200,000	.04	48,000.00
Machinery				400,000.00			450,000.00
Buildings				120,000.00			150,000.00
Pumping at lock No. 7				100,000.00			
Foundation for lock No. 7				250,000.00			
Stone pitching in basin	cubic yards	9,600	2.00	19,200.00	9,600	2.00	b19,200.00
Fender piles	number	4,080	13.50	55,080.00	4,080	13.50	b55,080.00
Fender wales	cubic feet	14,795	.50	7,398.00	14,795	.50	b7,397.50
Back filling at locks					600,000	.60	360,000.00
Dam across Rio Grande				140,000.00			
Concrete dam and weir at Lock No. 4	cubic yards				7,700	9.00	69,300.00
Movable dam	linear feet				133	100.00	13,300.00
Paving in bed of channel below weir	square yards				4,400	5.00	22,000.00
Guard gates in west divide				300,000.00			b300,000.00
3 drawbridges				60,000.00			100,000.00
Receiving basin for Espinal				7,000.00			b7,000.00
Receiving basin for Guachipilin				11,000.00			b11,000.00
Receiving basin for La Flor Creek				11,000.00			
Culvert or weir for Tola				90,000.00			
Drains at foot of canal banks				35,200.00			b35,200.00

[a] 3 locks, with lifts of 25, 42.5, and 42.5 feet, from mean tide to summit level.

[b] Company's estimate assumed.

[c] In company's estimate, 4 locks with lifts of 25, 30, 30, and 25 feet from mean tide to summit level. In Board's estimate, 4 locks with lifts of 20, 30, 30, and 30 feet from mean tide to summit level.

[d] For 2 locks.

Estimate—Continued.

WESTERN DIVISION—Continued.

[From Lake Nicaragua to the Pacific Ocean.]

	Company's estimate, 1895.			Board's estimate, 1895.		
	Quantity.	Unit price.	Cost.	Quantity.	Unit price.	Cost.
LAKE NICARAGUA TO TIDE LOCK AT BRITO—continued.						
Low level line—Continued.						
Right of way			$50,000.00			a $50,000.00
Railroad, single track, narrow gauge ... miles	18	$25,000.00	450,000.00			
Railroad, double track, standard gauge ... do				18	$50,000.00	900,000.00
Sidings ... do				4	10,000.00	40,000.00
Stations, shops, etc						81,000.00
Telegraph ... miles	18	500.00	9,000.00	18	500.00	9,000.00
Total Lake Nicaragua to tide lock at Brito, via low level line			18,628,130.00			23,788,273.45
BRITO HARBOR.						
Tide lock to Pacific:						
Dredging ... cubic yards	6,725,564	.20	1,345,113.00	6,750,000	.25	1,687,500.00
Stone in breakwaters ... do	383,899	1.50	575,848.00	1,690,000	1.50	b 2,535,000.00
Stone pitching ... square yards				23,000	2.00	46,000.00
Wharves						100,000.00
Machine shop						20,000.00
Warehouse						10,000.00
Total Brito Harbor			1,920,961.00			4,398,500.00
RECAPITULATION, WESTERN DIVISION.						
(1) Via Tola Basin line:						
Lake Nicaragua to tide lock at Brito			15,772,480.00	(c)	(c)	(c)
Brito Harbor			1,920,961.00	(c)	(c)	(c)
Total, western division, via Tola Basin line			17,693,441.00			
(2) Via low level line:						
Lake Nicaragua to tide lock at Brito			18,628,130.00			23,788,273.00
Brito Harbor			1,920,961.00			4,398,500.00
Total, western division, via low level line			20,549,091.00			28,186,773.00

LIGHTS AND BUOYS.

From the Caribbean to the Pacific			$373, 000. 00			$500, 000. 00

MANAGEMENT AND ENGINEERING.

From the Caribbean to the Pacific			(d)			$4, 000, 000. 00

HOSPITAL SERVICE.

From the Caribbean to the Pacific			(d)			$1, 000, 000. 00

GRAND RECAPITULATION.

	Company's estimate, 1895, Tola Basin line.	Company's estimate, 1895, low level line.	Board's estimate, 1895, low level line.
Eastern division	$31, 399, 844. 00	$31, 399, 844. 00	$51, 306, 295. 00
Lake and river division	5, 922, 782. 00	5, 922, 782. 00	26, 234, 343. 00
Western division	17, 693, 441. 00	20, 549, 091. 00	28, 186, 773. 00
Lights and buoys	373, 000. 00	373, 000. 00	500, 000. 00
Management and engineering			4, 000, 000. 00
Hospital service		5355127	1, 000, 000. 00
	55, 389, 067. 00	58, 244, 717. 00	111, 227, 411. 00
Contingencies, 20 per cent	11, 077, 813. 00	11, 648, 943. 00	22, 245, 482. 00
Grand total	66, 466, 880. 00	69, 893, 660. 00	133, 472, 893. 00

a Company's estimate assumed.
b Price includes cost of trestle.
c No estimate.
d Included in contingencies.

APPENDIX A.

MINUTES OF THE NICARAGUA CANAL BOARD.

Washington, D. C., Tuesday, April 23, 1895.—The members of the Board met at the State Department for informal conference.

Wednesday, April 24.—In the forenoon reported in person to the Hon. W. Q. Gresham, Secretary of State.

At 4 p. m. called upon Comptroller Bowler at the Treasury Department in reference to the general subject of expenditure and accounts.

Thursday, April 25.—In the forenoon received commissions and letter of instructions from the Secretary of State, and took oath of office.

At 2.30 p. m. reported in person to the President.

Friday, April 26.—In the forenoon called upon the Hon. Hilary A. Herbert, Secretary of the Navy, who tendered the use of the U. S. S. *Montgomery* as a means of transportation to and from Central America.

Engaged Mr. F. P. Davis, C. E., to accompany the Board to Nicaragua as chief of party.

At 4 p. m. Messrs. Ludlow and Noble left Washington for New York; Mr. Endicott to follow on Monday.

New York, Saturday, April 27, 1895.—By the courtesy of Lieutenant-Colonel Gillespie, Corps of Engineers, were permitted use of an office room on the seventh floor of the Army Building.

At the offices of the canal company, No. 54 Broad street, examining plans, etc., with the aid of Mr. Menocal, chief engineer of the company, and Mr. Bennett, his assistant.

Monday, April 29.—Mr. Endicott arrived from Washington, and Mr. Davis reported for duty.

The Board organized, and upon nomination of Mr. Endicott, Brevet Lieutenant-Colonel Ludlow was elected chairman. Mr. Davis appointed secretary pro tempore. Official account opened with the assistant treasurer at New York in the name of the chairman, who had been designated by the Secretary of State to act as disbursing officer for the Board.

Tuesday, April 30.—Board at canal company's offices with Mr. Menocal examining plans and records. Met Mr. Atkins, secretary of the company.

Wednesday, May 1.—Stenographer engaged temporarily. Mr. Chester Donaldson engaged as clerk to accompany freight and supplies by steamer to Greytown.

Passed Assistant Surgeon Stitt, U. S. N., under orders from the Navy Department to accompany and attend the Board and party to and from Central America, reported by letter and telegram, and was instructed to report in person at Mobile on May 7.

Board at canal company's offices examining plans, etc. Mr. Davis making purchases of outfit, stores, etc.

Thursday, May 2.—Bought $4,000 letter of credit from Brown Bros. & Co., of New York, for use in Nicaragua. Ordering supplies and engaging party.

Friday, May 3.—Mr. Reading Stoddart engaged as secretary to the Board.

Saturday, May 4.—Shipped supplies, instruments, provisions, and general outfit on board the steamer *Wylo*, which sailed for Greytown, Nicaragua, at 5 p. m., with Mr. Donaldson in charge of the Board's freight, and Mr. Bennett in charge of the canal company's maps and plans intended for use in the field.

Sunday, May 5.—Having completed its preparations, the Board left New York for Mobile, where the *Montgomery* was waiting with orders for Greytown.

Tuesday, May 7.—The Board and party reached Mobile at 5 a. m. Personnel as follows: Messrs. Ludlow, Endicott, and Noble, of the Board; P. A. Surg. Edward R. Stitt, U. S. N.; Reading Stoddart, secretary; F. P. Davis, chief of party; B. A.

Wood, assistant engineer; H. R. Stanford, transitman; L. L. Parke, levelman; Charles Williams, porter.

The Board was also accompanied by Mr. A. G. Menocal, chief engineer of the canal company, and his son, Mr. Edward Menocal.

The *Montgomery* lay at the wharf, and the Board advised Commander Davis of its arrival and readiness to come on board at any time. A steam launch, which was en route from Norfolk, arrived at 10 a. m., and the Board was informed that the ship would sail at 4 p. m.

At 3 p. m. Commander Davis called on the Board at the hotel, and at 4.30 p. m. the *Montgomery* left for Greytown.

Monday, May 13.—After fine weather throughout the voyage, the *Montgomery* anchored in 7 fathoms off the Greytown entrance at 12.30 p. m., and at 3 p. m. the Board and party were landed with their luggage, under guidance of a local cockswain, over a tolerably smooth bar, with 4 to 4½ feet of water, in two of the ship's cutters and the whaleboat.

The Board was received with a salute of 11 guns, and met at the steamboat landing by General Rivas, the governor of the Free Zone; the United States consul, Thomas O'Hara; the British consul, Mr. H. F. Bingham; Messrs. Sonnenstern and Weist, commissioned by the minister of public works to meet the Board, and by Messrs. Weiser and Von Braida, of the canal company.

The Board had offices and quarters at the house of Messrs. Hoadley, Ingalls & Co., represented by Mr. E. Z. Penfield; the remainder of the party in other lodgings, and board was engaged at the Victoria Hotel.

Tuesday, May 14.—At 10 a. m. the Board, accompanied by Mr. O'Hara, made a formal call on the governor; were received with great courtesy, and on leaving were given a salute of 6 guns.

Throughout Central America the hours of meals are almost invariably, coffee at 6 a. m., breakfast at 11, and dinner at 5 p. m., and work of all kinds arranges itself with reference to these hours.

At noon the Board, with Mr. Menocal, visited the "breakwater," and made inspection of that and other features of the entrance and harbor, including the short piece of canal.

Wednesday, May 15.—Started the party on a transit and stadia survey of the shore line eastward of the entrance. The Board examined the company's buildings north of the canal and the shore line in front of them.

At 2 p. m. the *Wylo*, with freight from New York, arrived; but in the absence of the tug *Coburg*, which, with a lighter, constitutes the means of landing freights at Greytown, the *Wylo* was unable to discharge, and therefore sailed again for Bluefields, to return later.

At 6.30 Governor Rivas, with the secretary and interpreter, Mr. Barton, called on the Board at its quarters, and at 7 Mr. Weist called to present the following credentials:

[Translation.]

NATIONAL PALACE,
Managua, April 20, 1895.

Engineers Don MAXIMILIANO SONNENSTERN and Mr. JULIUS WEIST, *Present:*

On the 25th of the present month you will proceed to San Juan del Norte (Greytown) as commissioners of this Government, in order to receive, accompany, and give any information they should like to the engineers of the United States Government sent to this country to study the route of the interoceanic canal and inform their Government of everything concerning it.

The present note is sufficient credential to you for the commission of engineers and all the authorities of the Republic to carry out your commission.

I am, sincerely,

ALONZO,
Minister of War and Public Works.

The Board was glad to avail itself of the minister's attention, and were indebted later to Mr. Weist for much assistance and information.

Thursday, May 16.—At 7.40 a. m. the Board, accompanied by Messrs. Menocal and Von Braida, made an inspection of the railroad line westward from the machine shops, for 11½ miles, to beyond Camp No 7, between the sites of Locks Nos. 1 and 2.

The party were conveyed on a pump car and a flat car, propelled by poles, and made the outward journey in three hours, returning under a pouring rain at 2.30 p. m.

At 7 p. m. the Board called on Don Maximiliano Sonnenstern, who was confined to his room by an accident.

Friday, May 17.—Board inspected the west shore line to the Indio River.

Saturday, May 18.—Examined the Harbor Head Lagoon at outer beach. Party surveying the west beach.

At 1 p. m. the *Wylo* returned, and the chairman of the Board went off to her in the *Coburg*, and thence to the *Montgomery* to inform Captain Davis that the shore lines east and west had been surveyed in readiness for the hydrographic survey which the Navy Department had directed for the use of the Board. Lieutenant Lyman, the navigating officer, was instructed by Captain Davis to take charge of the survey.

At 2 p. m. Messrs. Endicott, Noble, and Menocal inspected the company's dredges lying in the lagoon near the entrance.

In the evening, arranged a provisional itinerary for the inspection of the eastern division of the canal between Greytown and the San Juan River, at Ochoa, to cover a period of about three weeks.

Sunday, May 19.—Lieutenant Lyman came ashore to arrange in reference to survey, etc. Party engaged in platting the coast line from the transit and stadia line. Called on Mr. Pellas, proprietor of the River Transportation Company. A boat, the *Irma*, expected down to-day, and arrived at noon, but would sail again early Monday morning.

Monday, May 20.—The party finishing the platting of the coast line: The *Irma* sailed at 6.30 a. m., but a larger boat, the *Hollenbeck*, arrived at 2 p. m., and arrangements were completed with Mr. Pellas for the transportation of the Board and party to the west shore of the lake.

Tuesday, May 21.—The *Hollenbeck* left at 7.45 a. m. with the Board and party, accompanied by the Messrs. Menocal, Bennett, and Wieser, of the canal company, and Mr. Weist, of the Nicaragua department of public works.

The river steamers are of the Pittsburg type, and built there—sternwheel, high pressure, light draft and open decks, the lower for freight and steerage passengers, the upper for cabin passengers.

The junction with the Colorado River, 18 miles from Greytown, was reached at 12.30; the mouth of the Sarapiqui at 3.45.

At 6 p. m. stopped at Maineri's ranch on the right (Costa Rican) bank, opposite the mouth of the San Francisco River, and met Mr. Perez, of the canal company, who is engaged in cutting out the lines on the eastern division, and expected to have it done in about ten days.

At 8.30, tied up for the night to the right bank, below the mouth of the San Carlos River.

Wednesday, May 22.—Under way at 4.30 a. m., passing the broad mouth of the San Carlos, and at 7.40 stopped at the foot of the Machuca Rapids, where transfer had to be made to a lighter for ascent of the rapids, the depth being insufficient for the steamer.

At El Guis, at the head of the rapids, transferred again to the *Adele*, and at 2 p. m. left for Castillo.

At 4, when nearing Castillo, which is a Nicaraguan military station and customhouse, the Nicaraguan flag was hoisted on the jackstaff and the United States ensign on the quarter. Arrived at Castillo at 5 p. m., and were met by the commandante, Colonel Pacheco, and by the intendente, Don Ignacio Vosconcelos, who invited us to occupy quarters for the night on shore, and were very hospitable.

Thursday, May 23.—The Castillo Rapids can not be ascended by steamer, and transfer is effected by a tramway.

Left Castillo 6.45 a. m. in the small steamer *Norma*, with a lighter alongside, for the Toro Rapids. At 9.15 a. m. reached the lower end of Toro Rapids, and dropped the lighter to be poled up; and at 9.45 the *Norma* reached the head of the rapids at the mouth of the Savalo, where another transfer was made to the larger steamer, the *Managua*, en route to Fort San Carlos on the lake shore, where, at 5 p. m., the commandante, Colonel Saenz, came on board to extend official welcome. San Carlos is also a military post, and commands a fine view of the broad expanse of the lake and the ranges of Costa Rican Mountains in the distance.

At San Carlos, the Board had to await the arrival of the lake steamer *Victoria*, and meanwhile occupied the time, as at every other point where opportunity offered, in making full observations relative to the physics of the route, leveling to water marks, and noting other matters of interest.

The Board returned Colonel Saenz's visit, and were entertained at his headquarters.

Friday, May 24.—Examined the Rio Frio in the *Managua;* leveled to water bench mark for high and low stages of lake, and in the afternoon took soundings and observations of bottom in lake offshore channel.

Saturday, May 25.—Current and gauge observations of the San Juan.

Sunday, May 26.—Made a second gauging of the river. The *Victoria* arrived at 3.15 p. m., and at 11.30 sailed for San Jorge, the landing on the west shore near Rivas.

Monday, May 27.—At 6.30 a. m. passed Madera and Ometepe, and at 9.20 landed the party at San Jorge, the Board continuing to Granada, which was reached at 3 p. m. By the courtesy of the Government, a special train took the Board to Managua at 8 p. m.

Tuesday, May 28.—At 9 a. m., had a special audience with the President and the members of his cabinet, at the palacio, and were tendered the freedom of the State telegraph and the use of the Government steamer *El 93*.

At 10.15 a special train returned the Board to Granada, and at 11.30 the *Victoria* sailed again for San Jorge, and arrived at 6.40 p. m. The Board proceeded by tramway to Rivas, and were quartered at the capacious house of the Señora Runnels, with the entire party.

Wednesday, May 29.—The freight and provisions were sent out in five caretas, three to the hacienda Gamas, near Brito, and two to the intermediate camp that had been prepared at Paraiso.

After breakfast the Board and party left Rivas on horse and mule back for Brito, and reached the hacienda at 4.30 p. m.

Thursday, May 30.—Occupied the day in inspecting the Brito harbor and vicinity.

Friday, May 31.—Examined the canal route up the Rio Grande Valley, giving special attention to the La Flor Dam and adjacent lock sites, and camping at Paraiso.

Saturday, June 1.—Followed canal line to lake shore, examining proposed sites for dams, etc., for diversion of the upper Rio Grande, and at 4 p. m. left the lake for Rivas, where we arrived at 7.

Sunday, June 2.—Party taking levels and other measurements on lake shore.

Monday, June 3.—Telegraphed minister of public works asking for use of *El 93* for to-morrow.

Tuesday, June 4.—*El 93* did not come till 3 p. m., and arranged for trip in lake for to-morrow. Telegraphed to ascertain as to arrival of *Victoria* to take Board back to San Carlos.

Wednesday, June 5.—At 7.30 a. m. took *El 93* and examined harbor under lee of Ometepe Island. Took soundings, etc. Landed at Moyagalpa, an Indian village on northwestern end of Ometepe, and returned to Rivas at 6.30 p. m.

Thursday, June 6.—Arranged for departure. *Victoria* arrived at 3.30 p. m. and sailed at 7.30, anchoring for the night off Moyagalpa.

Friday, June 7.—Left Moyagalpa, and reached San Ubaldo on the east shore of the lake at 6 a. m. Arrived at San Carlos at 4 p. m.

Saturday, June 8.—Left in the *Managua* down river at 3.30 a. m. At head of Toro Rapids transferred to the *Norma*, and left for Castillo at 10. At 11.45 reached Castillo. Transferred to the *Adele* below the rapids, and lay for the day and night.

Sunday, June 9.—Left in the *Adele* at 6.15 a. m. Reached El Guis, at head of Machuca Rapids, at 7.45; lightered down, and transferred to *Hollenbeck*, and sailed again at 9 a. m.

At 11.15 landed at the camp on left bank at site of the Ochoa Dam. Was met by Messrs. Perez and Von Braida, of the canal company, and by Professor Pittier, of Costa Rica, with greetings from the President and letters from United States Minister Baker.

Messrs. Stoddart, Wood, and Parke, of the Board's party, continued down river to Greytown to make survey of the lagoon.

At noon the Board inspected the canal line for 1¼ miles; then crossed to embankment line, and thence back to camp—about 4 miles of very hard travel in four hours.

Monday, June 10.—At 6.30 a. m. crossed the San Juan to right bank, and went out on line of Ochoa Dam and San Carlos Ridge. At 4.30 made camp 7 miles out.

Tuesday, June 11.—Left camp at 6.40 and went over 3 miles of crest line. Struck down to the San Carlos, and returned in two canoes to the Ochoa camp at 2 p. m.

Wednesday, June 12.—Left camp at 7 a. m. Said farewell to Professor Pittier, and followed canal and embankment line to camp on west bank of Danta. Tried to examine the Florida Lagoon in a small canoe, but heavy grass prevented.

Thursday, June 13.—Inspected canal and embankment line, and reached camp on left bank of San Francisco at 12.30.

Friday, June 14.—Inspection of line and streams in vicinity of San Francisco camp, returning to same at night.

Saturday, June 15.—Examined line from San Francisco camp to Camp Carmen, on the right bank of the Limpio, the west slope of the east divide.

Sunday, June 16.—Route from Camp Carmen to Camp Alice, on the Lindo, near summit of divide.

Monday, June 17.—Crossed divide to Camp Miller, passing the summit at 8 a. m., and following down the Deseado.

Tuesday, June 18.—Trail to Camp Menocal, where stopped for breakfast only, and thence to Camp 7.

At 3 p. m. took flat car and went to Greytown, arriving there at 5 p. m. Engaged the *Hollenbeck* for trip to-morrow to mouth of Colorado River, and made arrangements for Messrs. Davis and Stanford, of the Board's party, to make a reconnoissance in the vicinity of the Serapiqui.

The harbor tug *Coburg*, constituting the only means of landing and shipping freight, was beached on the 17th outside the entrance and became a total wreck.

Wednesday, June 19.—The Board left at noon in the *Hollenbeck;* reached the Colorado junction at 5 p. m. and the mouth of the Colorado at 7.15, and lay for the night.

Thursday, June 20.—Board examined and surveyed mouth of the Colorado, and returning sketched the river to the junction, reaching Greytown at 4 p. m.

Friday, June 21.—Messrs. Davis and Stanford left in the *Hollenbeck* for the Serapiqui. The *Montgomery* not yet returned from Colon, where she had gone on the 15th for coal. The "bar" is ugly, and several little schooners are unable to get out.

Saturday, June 22.—Finished survey of lagoon and shore line.

Sunday, June 23.—Sent word to Captain Davis by canoe that the Board and party would come on board as soon as the transportation of freight and personnel by canoe could be accomplished. Got part of freight delivered and arranged for final transfer to-morrow.

Monday, June 24.—By aid of a small steam launch inside and a large canoe over the bar, which was formidable, got off safely, and sailed at 2 p. m. for Port Limon, arriving there at 11 p. m.

Tuesday, June 25.—Landed, and after conference with Mr. Walter Ingalls, arranged to leave in special car for San Jose in the morning.

Wednesday, June 26.—Left at 6.15 and arrived at San Jose at 1.30. Were received by United States Minister Baker and cabinet officers, and quartered as guests at the hotel. At 4 a special audience by the President, and at 7 the President and cabinet, with other guests, did the Board the honor of dining at the hotel.

Thursday, June 27.—Heavy rain during the night and landslides reported on railroad line. Carriages to inspect San Jose, its public buildings, schools, museum, and hospitals. Met Mr. Keith and Colonel Church of the Costa Rica Railroad.

Arrangements made to start down the line in the morning, notwithstanding the landslides and interruption to travel.

Friday, June 28.—Left at 6 a. m., under guidance of Mr. Williamson, superintendent of the railroad. Train to Juan Vinas, 29 miles from San Jose; thence hand car and walking. Met Mr. Hodgson, general manager of the railroad, to whose kindness and efforts the Board is indebted for getting through to Port Limon. Reached Turrialba at 1.30, and remained over night, sleeping on cots in the station.

Saturday, June 29.—At 6 a. m. started again with hand car and on foot. Reached Madre de Dios at 5.35 p. m. Left the party to follow, and Board pushed on to San Jose Creek, where got engine and car, and reached Port Limon at 10 p. m.

Sunday, June 30.—Party arrived at 8.20 a. m., and at 10 on board of *Montgomery;* sailed for Colon at noon.

Monday, July 1.—Arrived at Colon at 6.15 a. m. United States Consul Pearcy came on board, and, at his invitation, the Board accompanied him to his very comfortable quarters on shore.

Tuesday, July 2.—By the kindness of Colonel Rives, general superintendent of the Panama Railroad, the Board had a special train from Colon to Panama, stopping to examine certain points on the way. At Panama the canal company's engineers had proffered the use of one of the canal launches for inspection of the sea-level end of the canal.

Board returned to Colon by the special, having had an excellent opportunity, under Colonel Rives's personal guidance, to see the canal and railroad works.

Wednesday, July 3.—The Board, with Colonel Rives and Captain Davis, took a canal tug to the mouth of the Chagres River, and thence upstream and into the canal section, which was carefully examined.

Thursday, July 4.—The collier *Stag* arrived and the *Montgomery* was again able to coal.

Friday, July 5.—The *Montgomery* coaling.

Saturday, July 6.—The *Montgomery* coaling.

Monday, July 8.—The *Montgomery* completed coaling, and Board and party got baggage on board in readiness to sail.

Tuesday, July 9.—*Montgomery* sailed at 7.45 p. m. for Key West.

Sunday, July 14.—Anchored in Key West Harbor at 1.15 p. m. The State quarantine refused all communication with shore except by the health officer's boat, but permitted the navy coal barges to come off and fill the *Montgomery's* bunkers again. The Board not allowed to go to Tampa and thence northward.

Tuesday, July 16.—*Montgomery* finished coaling.

Wednesday, July 17.—*Montgomery* sailed for New York at 4.45 p. m.

Sunday, July 21.—*Montgomery* anchored off Forty-second street in the North River, New York, at 2.30 p. m., and the Board and party landed the same afternoon.

The Board's party was disbanded, Messrs. Davis, Stanford, and Stoddart being retained for the work of preparing the report.

The members took a brief vacation to see their families, the chairman proceeding to Washington to report the return of the Board to the United States.

Tuesday, July 30.—The Board reassembled at the Army Building in New York, and by the courtesy of Colonel Moore, of the Quartermaster's Department, was temporarily allotted offices on the fourth floor, as well as the drafting room, on the seventh floor.

Until October 31 the Board was engaged in the laborious work of a thorough investigation of the canal company's maps and data, and all other available sources of information, and in the preparation of its report, which was completed on the night of October 31, and on November 1 submitted through the State Department and delivered to the President.

Throughout the entire investigation the officers of the canal company have furnished every assistance in their power.

APPENDIX B.

NICARAGUA CANAL BOARD,
Army Building, New York, July 31, 1895.

DEAR SIR: The Nicaragua Canal Board is now in New York, prepared to enter at once upon the examination of the data requisite for the preparation of its final report to the President.

The time allotted is but brief, and a very large amount of material must be examined. The Board would be much indebted if you would give such instructions as may be necessary to place at our disposition any of the company's data that may be of record in New York or elsewhere; and I beg to suggest that, in order to facilitate our labor as much as possible, at the least inconvenience to the company's officers, you authorize the secretary of the company, Mr. Atkins, who evinces every disposition to accommodate us and to whom we are already indebted for courtesies, to permit us to make requisition upon him from time to time for such material as we may need, and to retain it in our possession while the data in question are under consideration.

As chairman of the Board, I will give memorandum receipts for such maps and other data as we need from time to time, and the Board will be responsible for their safe return to the company's offices.

The temporary offices of the Board are in the Army Building, in Whitehall street, which, as you are probably aware, is a fireproof structure, and whatever material we have in our possession will be securely kept under lock and key.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

HIRAM HITCHCOCK, Esq.,
President Maritime Canal Company, 54 Broad Street, New York.

THE MARITIME CANAL COMPANY OF NICARAGUA,
54 and 56 Broad Street, New York, August 1, 1895.

DEAR SIR: I have your favor of July 31, and in reply will say that it gives this company much pleasure to comply with the request therein contained.

Mr. Atkins, the secretary of the company, will gladly respond to the requisitions your committee may make upon him from time to time.

Please command me personally if I can at any time be of service to you.

Very truly, yours,

HIRAM HITCHCOCK, *President.*

Col. WILLIAM LUDLOW,
Chairman of the Nicaragua Canal Board.

NICARAGUA CANAL BOARD,
Army Building, New York, August 2, 1895.

DEAR SIR: I beg, in behalf of the Board, to thank you for your very kind letter of yesterday, placing at our disposition any information in the possession of the company.

If at any time you are down town in the vicinity of the Army Building, it would give the members of the Board much pleasure to meet you personally.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

HIRAM HITCHCOCK, Esq.,
President, 56 Broad Street, New York.

NICARAGUA CANAL BOARD,
Army Building, New York, August 3, 1895.

DEAR SIR: Will you be good enough to send to me for the use of the Board one copy of profile of location line of lower route from Ochoa to San Juanillo, survey of 1888?

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

THOMAS B. ATKINS, Esq.,
Secretary Maritime Canal Company, 56 Broad Street, New York.

NICARAGUA CANAL BOARD,
Room R 4, Army Building, New York, August 7, 1895.

DEAR SIR: The Board would be glad to take up at once the question of the construction of the Ochoa Dam, and would be very much obliged to you if you could come over to-morrow at any time after 10 o'clock, or, if to-morrow would be impracticable for you, at any time Friday morning between 10 and 1.

The subject is one of such magnitude and importance to the canal project that it is expedient to consider it as fully as possible, and the Board will be glad to avail itself of your assistance in considering details of construction and investigating the circumstances of similar constructions elsewhere.

I have written to the office to ask Mr. Bennett to bring over all the data he has with reference to the matter.

With much regard, very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

NICARAGUA CANAL BOARD,
Army Building, New York, August 7, 1895.

DEAR MR. BENNETT: The board would be glad to have you bring over to-morrow all the data appertaining to the Ochoa Dam, including such drawings, borings, estimates, and reports as there may be bearing upon the subject of its location and construction.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company,)
56 Broad Street, City.

NICARAGUA CANAL BOARD,
Army Building, New York, August 7, 1895.

DEAR MR. BENNETT: The Board would be glad if you would let us have all the data relating to river gaugings, including field notes, computations, and reports.

I fear that we shall be making a good many demands upon your time, and I would suggest that you might, if you please, be getting the information together, en bloc, relating to the various subjects. For example, the drawings, notes, plans, reports, borings, cross sections, etc., with reference to the San Carlos Ridge—a subject susceptible of being considered by itself. If all the information with regard to those were collected, examination of it would be much facilitated.

If practicable we would like to have the gauging data as early to-morrow as it would be convenient for you to deliver it, and in particular we would like to have the gauging of the San Juan River, to which you and Mr. Menocal referred the other day.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company,)
56 Broad Street, New York.

NICARAGUA CANAL BOARD,
Army Building, New York, August 13, 1895.

DEAR SIR: Will you please furnish the Board with the following: Baldwin's survey of beach from La Fe to Indian River; Ehle's survey of same, showing property lines?

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care the Maritime Canal Company,)
54-56 Broad Street, New York.

NICARAGUA CANAL BOARD,
Army Building, New York, August 14, 1895.

DEAR SIR: Will you please send to the Board the following: San Carlos Ridge plan and profile, with cross sections, etc.; plans, profiles, and cross sections from Ochoa to Locks; Estimates of January 31, 1890, see Senate Report No. 1142, of December 22, 1892), as revised to date?

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company,)
54-56 Broad Street, New York.

NICARAGUA CANAL BOARD,
Army Building, New York, August 14, 1895.

DEAR SIR: Could you conveniently furnish the Board with your latest revision of the estimates for the canal?

The most recent data that we have for dimensions and cost are those given in your report on final location, corrected to January 1, 1890.

Several modifications and revisions have been made since that date, and we would be glad to have the results.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

UNITED STATES NAVY-YARD,
New York, August 15, 1895.

DEAR SIR: Replying to your letter of the 14th instant, I beg to say that I will have a copy of the revised estimates for the canal made and forwarded to you at an early date.

Very truly, yours,

A. G. MENOCAL.

Col. WILLIAM LUDLOW,
United States Engineer, Chairman Nicaragua Canal Board.

NICARAGUA CANAL BOARD,
Army Building, New York, August 17, 1895.

DEAR SIR: The sundry civil act, approved March 2, 1895, under which the Nicaragua Canal Board was organized, contains the following provisions:

"For the purpose of ascertaining the *feasibility, permanence, and cost of the construction and completion* of the Nicaragua Canal by the route contemplated and provided for by an act which passed the Senate January 28, 1895, entitled 'An act to amend the act entitled "An act to incorporate the Maritime Canal Company of Nicaragua," approved February 20, 1889,' * * *

"And the said Board, under such arrangements and regulations as shall be made by the Secretary of State, with the approval of the President of the United States, shall visit and personally inspect the route of the canal, *examine and consider the plans, profiles, sections, prisms, and specifications for its various parts,* and report thereon to the President."

The Board has complied with the requirement for a personal inspection of the route, and is now engaged upon the second stage of the investigation, viz, the examination and consideration of the plans, specifications, etc., for the several parts of the canal and its adjuncts, as indicated by underlinings in the quotations above made from the act, in order to the formation of an adequate judgment as to the feasibility, permanence, and cost of the constructions as proposed by the company.

In entering upon the consideration of these data, it is found that your "Report on the final location of the canal," revised to January 31, 1890, is the latest official paper that states the general plan of the company, with explanations of the engineering features of the projected constructions and estimates of their cost.

It is known to the Board, from your Columbian Congress paper entitled, "The Nicaragua Canal," from conversations with you and otherwise, that several material modifications have been made since the date of your report of 1890, in locations, methods of construction, and other engineering data, and it is essential, in order that the Board may conform to the purpose of the act, that it should know specifically, definitely, and in detail what the company now proposes to do, according to its latest information and study, and how it proposes to do it.

The Board suggests, as a convenient means of accomplishing this with the least trouble to you, that you review the report of 1890, page by page, and where the present plans, purposes, data, and computations of the company vary from those given, the differences be noted and fully stated in writing, and the results traced to their conclusions as affecting both engineering methods and details of construction, and the final estimates of cost.

In the case of important constructions also, such as heavy embankments and dams, and the locations and dimension of weirs and sluices, etc., data and computations of the natural forces in question and their effects, are needful to the proper understanding of the matter, as well as detail drawings of the work proposed, and the specifications for the construction of their several parts.

The Board regrets to trouble you, when otherwise engrossed with work in your charge, but the requirements of the act, the limited time available, and the magnitude and public importance of the task imposed upon the Board must serve as its excuse.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

NICARAGUA CANAL BOARD,
Army Building, New York, August 17, 1895.

DEAR SIR: Will you please furnish the Board with tracing of the western division, scale 400 feet to an inch, from which the blue print which we have was made?

If convenient, the messenger will bring it.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company,)
56 Broad Street, New York.

NICARAGUA CANAL BOARD,
Army Building, New York, August 19, 1895.

DEAR SIR: Will you be kind enough to furnish the Board with a copy of the detailed report made by Asst. Engineer H. C. Miller in July, 1893, and any other reports you may have on the subject of borings?

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care the Maritime Canal Company,)
56 Broad Street, New York.

NICARAGUA CANAL BOARD,
Army Building, New York, August 19, 1895.

DEAR SIR: The Board desires to use for a few days the original map of the eastern division which we saw at Greytown for the purpose of reproducing it on a smaller scale for the use of the Board.

It is understood that this map is very valuable, and it will be practicable to arrange for its return to you at the close of each day's work, if that is considered necessary.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care the Maritime Canal Company,)
56 Broad Street, New York.

NAVY-YARD, *New York, August 21, 1895.*

DEAR SIR: I beg to forward herewith copy of the revised estimates of the Nicaragua Canal, as requested.

Your letter of August 17 has been received, and I will give it my consideration at the earliest opportunity.

Yours, very truly,

A. G. MENOCAL.

Col. WILLIAM LUDLOW,
Corps of Engineers, Chairman Nicaragua Canal Board.

NICARAGUA CANAL BOARD,
Army Building, New York, August 23, 1895.

DEAR MR. BENNETT: The readings of the river gauge and records of rainfall at Camp Carazo are probably the most important that were taken by the company, and will be extremely useful in the consideration of the river physics.

The Board would be glad if you would make special endeavor to procure this record and let us have it.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company,)
54 Broad Street, City.

NICARAGUA CANAL BOARD,
Army Building, New York, August 23, 1895.

DEAR SIR: I beg to acknowledge with thanks the receipt of your note of August 21, forwarding, in compliance with the request of the Board, revised estimates for the canal.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

NICARAGUA CANAL BOARD,
Army Building, New York, August 23, 1895.

DEAR MR. BENNETT: Much obliged for the profile you sent of the rainfall at Carazo for the six months ending December, 1888.

Are there not records prior to this, filling out the full year, and possibly back of that? My understanding was that there was a complete record from December 1, 1887. Please see if you can recover this.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company,)
54 Broad Street, City.

NICARAGUA CANAL BOARD,
Army Building, New York, August 24, 1895.

DEAR MR. BENNETT: If practicable, the Board would like very much to know what was the actual cost of the work of construction done by the company, say under the following heads:

What did the railroad, as built, cost per mile?

What did the dredging done cost per yard?

What did the pier cost per foot?

What did the telegraph line cost per mile?

If you have this information, please furnish it, and at the same time indicate what items of cost are included in the several totals.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company,)
54–56 Broad Street, New York.

NICARAGUA CANAL BOARD,
Army Building, New York, August 24, 1895.

DEAR SIR: It is observed that the revised estimates which you were good enough to send the other day provide for the La Flor Dam practically as heretofore proposed, but with the addition of a masonry core and the wasteweir.

Will you please supplement this information by the alternative estimate for a canal in the western division without the aid of the La Flor Dam?

I understood you to say when we were in Nicaragua that you had made plans and estimates for this, in anticipation of the necessity for abandoning the La Flor Dam project. If so, the Board would be glad to receive this at your early convenience.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

NAVY-YARD, *Brooklyn, N. Y., August 25, 1895.*

DEAR SIR: Your favor of yesterday received and contents noted. I leave this afternoon for Washington on official business, to be gone, I think, one or two days, and can not give the matter my immediate personal attention, but I have instructed Mr. Bennett to furnish you the profile and computations for the alternative plan for a canal in the western division without the aid of the La Flor Dam.

In this connection I beg to say that while the result of the borings lately taken at La Flor shows that the original plan for a dam at that point must be considerably changed to meet the conditions, as shown by the borings, the company has not yet abandoned the idea of the dam, and will resort to a canal wholly in excavation through the valley of Tola only when more exhaustive investigations of the physical conditions prove the latter to be the safest and best plan.

The difference in the cost of the two plans under consideration would not in any case materially alter the total in the estimates.

I had expected to be able to send you before now the information called for in your communication of August 17, but pressing official duties and inability to do work in the evening for the last few days compel me to ask your indulgence for a short time more.

Yours, truly,

A. G. MENOCAL.

Col. WILLIAM LUDLOW,
United States Engineers, Chairman Nicaragua Canal Board, New York.

NICARAGUA CANAL BOARD,
Army Building, New York, August 28, 1895.

DEAR MR. BENNETT: Will you be good enough to let us have the following data:

1. Any tide, current, or wind observations made at Brito, showing maximum range, direction, etc.

2. (*a*) The abstract of bids received for dredging, pursuant to specifications; (*b*) name of contractor and amount of contract; (*c*) how much work was done thereunder.

3. Any data of record with reference to the alternative location of the canal between Greytown and the divide, as proposed by Mr. Davis.

It is important, if practicable, to procure the additional data with reference to the San Juan River gauging. Please make every effort to find this.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company,)
54 Broad Street, City.

THE MARITIME CANAL COMPANY OF NICARAGUA,
54 Broad street, New York, August 29, 1895.

DEAR SIR: In reply to your letter of August 24, asking for prices of work actually executed by the canal company I give you the figures below:

The 11.5 miles of railroad built cost $372,728.73, or $32,411.19 per mile. This includes material, freight, labor, subsistence, superintendence, and location, but does not include rolling stock. The rolling stock cost $62,789.

727,861 cubic yards of dredging was done at a cost $80,029.07, or 11 cents per yard. This includes labor, subsistence, fuel, oil, waste, etc., material, and every cost incidental to the work.

937 linear feet of pier and approximately 200 feet of jetty were built for $174,507.85. Allowing $10,000 for cost of jetty, which is not reported separately, the pier cost $164,507.85, or $175.57 per linear foot.

66 miles of telegraph was built at a cost of $19,719.76, or $298.78 per mile. Labor, subsistence, material, superintendence, and maintenance of the line for about a year are included in this amount.

No contracts were let under the dredging specifications that you have.

Respectfully,

F. W. BENNETT.

Col. WM. LUDLOW,
Chairman Nicaragua Canal Board, New York.

NAVY-YARD, *Brooklyn, N. Y., September 2, 1895.*

DEAR SIR: Your requests by favor of August 17 have my attention.

Owing to the fact that all proposed modifications of the original plans and location of the canal have always been held, together with the original plans themselves, subject to such further modifications as increased knowledge of the problem should cause to appear desirable, we have only calculated the variation of the original estimate made by such modifications as have yet been proposed, both as to quantities and costs, without making in all cases final detail drawings of them.

In revising the estimates we have in some cases allowed, as is proper, a diminution of the unit values used in the original estimate, to make them approximate somewhat to the unit values established by recent inventions, discoveries, and appliances in dredging and in earth and rock work. They are not, however, reduced in any case to points warranted by the recognized cost to-day of similar work, but are maintained at a sufficiently high figure to assure the amplitude of the estimate.

In view of the fact stated in the earlier part of this communication, I am not prepared to give you the detail drawings for which you ask, but I am glad to furnish herewith such notes on the report of January 31, 1890, together with references to certain data of various kinds and computations pertinent thereto, as with that report and with the plans and drawings, etc., which have already been furnished you, will, I trust, present in an intelligible form "what the company at present proposes to do, and how it proposes to do it."

If in any respect I should fail to make either of these points clear I shall gladly respond to your further inquiries.

[Notes showing modifications made in location, methods of construction, and other engineering data, in Nicaragua Canal since the report of 1890.]

Pages 1 to 5 of report of January, 1890: Extensive additional surveys were made during the years 1890 and 1891. Also numerous borings in rock and earth on the axis of the canal and at the sites of the locks, dams, and embankments.

As the result of these investigations important local improvements were introduced in the original location of the canal, and in the locations and dimensions of the embankments, especially in the valleys of the Deseado and San Francisco.

The railroads from Greytown to Ochoa and from the lake to the Pacific were located more in detail.

The sites of all the embankments, dams, and locks were the subject of careful studies, as is attested by the numerous cross sections shown in the detail drawings.

These local changes have greatly improved the project, but the salient features of the original design remain practically as proposed in the report of 1890.

Page 6: There has been no change in the location of Locks Nos. 1 and 2. The lift of Lock No. 1 remains as originally proposed, 31 feet; but that of Lock No. 2 has been increased from 30 to 35 feet. The valley of the Deseado from Lock No. 1 to Lock No. 2 is partially flooded by the construction of nine low earth embankments and a concrete dam with two sluices. Diversion channels leading to and from these sluices will take the flow of the Deseado during the construction of the embankments, and the sluices, together with the weirs, will be ample to discharge the flood waters of the stream. The sluices will have two openings, 20 by 25 feet. Two concrete weirs, with an aggregate length of crest of 500 feet, have been placed in two gaps of the surrounding ridge. (For the discharge of weirs see Water Congress paper.)

Three embankments, one across the Deseado bottom and two in the gaps of the confining ridge, at Lock No. 2, form the Middle Deseado Basin, 4.4 miles long. A sluice with two openings and diversion channels, as in the case of the lower basin, will be built at this point. There will be wiers with 400 feet length of crest in the dividing ridge.

Lock No. 3 has been finally located just below Virginia Creek. At this point the hills approach so closely the banks of the Deseado that a single dam of about 700 feet crest length will close the valley, forming the Upper Deseado Basin. Lock No. 3, with a lift of 40 feet, is located on the south side of the stream at this point. This upper basin is at the summit level of the canal; it is not so large as formerly proposed, but it has ample superficial area to prevent undue fluctuations in the level of the water in the basin and in the canal while the lock is being operated. This upper dam will be built of concrete and will contain sluices with two openings 20 by 25 feet. A weir 400 feet long will be built in the adjoining hill to the north.

Page 7: The width of the divide-rock cut has been increased from 80 to 100 feet at the bottom, the slopes remaining as originally proposed for rock and earth.

Instead of rock-fill dams, it is now proposed to build clay embankments having in every case a top elevation of 8 feet above the surface of the water in the basins. They will have a top width of 12 feet if not over 8 feet high, 18 feet if not over 15 feet high, and 20 feet for all heights exceeding 15 feet. Water slopes of 3 to 1; dry slopes 2½ to 1. Top and water slopes to be paved with 2 feet of well-laid stones. All mud and surface soil to be removed, and all embankments resting on the valleys or swamp level will have three parallel rows of sheet piling between abutments. (See detail drawings.)

Page 9: See remarks on page 7 for embankments.

Six gaps will have to be closed with embankments, aggregating 3,440 feet in length, measured on the valley floor, and 13,685 feet on the crest. In addition to the above, there will be 51 smaller embankments, with a total length of crest of 16,745 feet.

Three waste weirs, of total length of 600 feet, are proposed to be built in favorable gaps in the confining ridge. Three sluices, with diversion channels low enough to drain the basin, are proposed for the flow of the Danta, San Francisco, Nicholson, and Chanchos during the construction of the embankments, each sluice to have two openings 20 by 25 feet.

Page 13: Remarks on page 7 apply to heights, sections, and method of construction of San Carlos embankments. The two large embankments spoken of in the text are to be replaced by dams of concrete, with sluices having bottom elevation of 62 feet above sea level, each dam to have two openings of 20 by 25 feet.

Three weirs, with 1,200 feet total length of crest, are provided at an elevation of 103.5 feet above sea level.

The total number of embankments required on the San Carlos ridge is 18, having a total length of 4,775.

See page 32 of paper on Nicaragua Canal, World's Columbian Water Congress.

All rock cuts on both the eastern and western section to be 100 feet wide at bottom.

Revised estimates to conform to these changes and provide for 10 additional miles of railroad from Greytown to Lock No. 1, not estimated for in the report of 1890, have been furnished to the Board as requested.

I will be pleased to forward any further information desired.

Yours, very truly,

A. G. MENOCAL, *Chief Engineer.*

Col. WILLIAM LUDLOW, U. S. A.,
Chairman of the Nicaragua Board, New York.

NICARAGUA CANAL BOARD,
Army Building, New York, August 29, 1895.

DEAR SIR: The Board would be glad to receive information with regard to the following points, to which I beg to invite attention:

(1) According to Childs's survey, the surface level of the river at Ochoa was 56.2; according to Lull's survey, the elevation was 53.75, and, as nearly as we can at present determine it from the company's data, the elevation at the time of Covode's gauging was 48.7.

These elevations show considerable disparities; but, with regard to Childs and Lull, the discharge reported by Childs is about double that reported by Lull at the time of their respective observations. These two, therefore, may be considered as fairly comparable.

The Covode's datum, however, is so much lower as to make it needful to get an explanation, if practicable, of the difference.

Covode's observed flow is nearly the same as Childs's, but his surface level is about 7¼ feet less and 5 feet less than Lull, who was noting a much lower stage of the river.

(2) The following discrepancies in distances are noted:

Childs gives the distance from the lake to Ochoa at 67.72. In your part of Lull's report, at pages 76 and 84, this distance is given at 64.52, and on page 77 at 68.31. The canal company's project gives it as 69, and the table of distances at 65.4. Some of these notations may be printer's errors.

We would be glad also to have information with reference to certain matters heretofore discussed orally, but not, as is observed, carried into the estimates.

(3) Is the diversion of the Upper Deseado during construction considered necessary; and if so, what plans have been made for it, and what is the cost?

(4) Similar information with regard to the Rio Frio.

(5) Similar information with regard to the Upper Rio Grande.

(6) What arrangements and cost to provide for the flow of the Tola in case a low-level canal is constructed.

(7) Similar data with regard to the Lower Rio Grande, to prevent, if needful, the discharge of the valley and the weir overflow at the Tola Dam from entering the sea-level canal or harbor.

(8) What is the estimated cost of the alternative low-level canal for the western division and its necessary adjuncts?

With much regard, very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

NICARAGUA CANAL BOARD,
Army Building, New York, September 6, 1895.

DEAR SIR: I beg to invite your attention to the following:

Your report of 1890 gives the amount of rock excavation under water in the river section at 398,613 cubic yards and the earth excavation under water at 2,150,900 cubic yards, and these same quantities are carried forward into the revised estimate recently furnished.

It has been understood that the deepening to be made in the river would have a base width of 125 feet, with slopes of 1 on 1 in rock and in earth 3 to 1, and that the depth of the finished channel was to be 28 feet, with the Ochoa Dam crest at 106 feet and the lake at 110.

A computation of the quantities above referred to made in this office, according to the company's cross section, shows 1,424,000 cubic yards of rock and 3,464,000 cubic yards of earth to be excavated.

The Board would be glad if you would have the computation remade according to the company's data, and advise me of the result, in order, if possible, to reconcile the very considerable disparities existing between our computation and the estimates.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

UNITED STATES NAVY-YARD,
New York, September 10, 1895.

DEAR SIR: Referring to your letter of the 6th instant, relative to the amounts of rock and earth excavation in the River San Juan, I beg to say that I have no reason to question the correctness of the computations made in your office.

The amounts given in the report of 1890, and transmitted to the revised estimates lately furnished you, were taken from the Government Report of Surveys of 1885, and any errors that may have been made in the computations have been carried inadvertently from the report into the new estimates.

It may be proper to say in this connection that excavations of rock under water should be estimated for only at Toro and Castillo rapids, where solid ledges are known to exist, the rock reported by the soundings at other places in the channel of the river being, in our opinion, loose stones or probably only pebbles and gravel.

With much regard, yours, truly,

A. G. MENOCAL,
Civil Engineer, United States Navy.

Col. WILLIAM LUDLOW,
United States Engineers, Chairman Nicaragua Canal Board.

NICARAGUA CANAL BOARD,
Army Building, New York, September 10, 1895.

DEAR SIR: Referring to your letter of September 2, furnishing certain data with regard to the revised estimates recently prepared, the Board regrets that final detail and construction drawings can not be furnished, and that no reference is made to the methods of construction to be employed in the case of the Ochoa and La Flor dams and the San Francisco embankments, but desires to avail itself of your offer of further information on the following points, viz:

(1) What are the reasons for adopting 120 feet as the bottom width for the Greytown Canal and other sections, and would not a less bottom width of, say, 100 feet, with turn-outs at suitable intervals, answer the purpose as well as the broader section without turn-outs?

(2) Why is 28 feet estimated at the full depth in the Greytown Canal and Harbor, the remainder of the navigation being apparently designed for a depth of 30 feet?

(3) What are the full depths and widths proposed for the several sections of the navigation from sea to sea, and from what datum plane of reference are the depths measured in the several cases?

(4) What are the depths and widths as actually provided for in the estimates, and to what datum plane are the computations made in the several sections? If the estimates in any case do not provide for securing the full depth, as proposed, what additions should be made to them for this purpose?

(5) In the outer harbor dredging at Greytown and Brito, is additional deepening considered necessary to allow for the rise and fall of waves, and what additions to the estimates are needed to provide for this?

(6) What is the minimum radius allowed for curvature in the navigation; what bends are to be cut off in the River San Juan, and what are the cross sections, borings, or other data on which the estimate of 422,500 cubic yards of earth excavation above water in the river valley is based?

(7) What terminal and landing facilities, if any, are to be provided at the two harbors and on the lake prior to the completion of the Brito and Greytown entrances, for the purpose of delivering and forwarding construction material, machinery, etc.; also, what wharves, shops, roundhouses, storehouses, etc., is it expected to construct, and at what estimated cost?

(8) What are the details of railways, sidings, etc., required to handle and distribute the materials of the two divides?

(9) What are the plant, appliances, organization, and methods to be used in the construction of the Ochoa and La Flor dams, including the deposit and arrangement of the materials, and what special means, if any, are proposed to secure the stability and permanence of these dams?

(10) What are the similar details with regard to the construction of the San Francisco and other embankments, and what precautions are to be taken to secure the solidification, impermeability, and maintenance of these structures?

(11) What are the present plans of the company with regard to the proposed change in position of the Chanchos embankment, it being understood that a new line has been found more advantageous than the present one?

(12) Has any change been made in the section of earth cuts between the east divide and Ochoa, scheduled as 80 feet wide in the report of 1890?

(13) Why are the fender wales, etc., omitted in the recent estimates in the rock cuts?

(14) Is it still intended to use the Ochoa Dam as a weir; and if not, what provision is to be made for the flow of the river?

(15) In the 1895 estimate for the Ochoa Dam it is observed that all the sheet piling, guides, etc., included in the 1890 estimate, and amounting to some $65,000, are omitted. Is this omission intentional?

(16) The 1890 estimate includes an item of over $600,000 for trestles to be used in the construction of the San Francisco embankments, and $55,000 in the Deseado embankment. The 1895 estimate omits these items without making any change in the unit price of earth embankment. Should not this price be increased if no provision is made for depositing the material?

(17) It would be desirable to have full details of the recently proposed San Carlos sluices, showing construction as well as their relation to the valley contours north and south of them, with elevations of the river and canal surfaces, etc.

(18) Final detailed drawings of the locks are desired, if procurable, with the view to the consideration of their dimensions and arrangements.

(19) Also such final detailed drawings as have been made of any portion of the work.

(20) In case of a low-level canal in the western division, what are the sections in various portions of it, and what passing places, if any, are to be provided, and with what width and length and at what distances apart?

(21) What further changes, if any, are proposed in the position of locks, with

special reference to the position of Lock No. 6, in view of the deep mud bottom at that point as shown by the borings.

(22) Referring to your letter of August 25, and particularly to the statement that the construction of the La Flor Dam would only be abandoned when more exhaustive investigations of the physical conditions prove that it would be safer to do so, the Board would be glad to be advised as to what further and additional surveys, gaugings, borings, etc., the company proposes at the site of the La Flor Dam and elsewhere, and at what points and for what special purposes these are to be made.

(23) What is the area of the lands above the La Flor Dam which would be overflowed by its construction, and what is the estimate of the damages to be paid?

(24) It is understood that the purpose of building the Ochoa Dam to elevation 106 is to maintain the level of the lake permanently at not less than 110. Upon what basis is it computed that the dam will accomplish this?

(25) With the lake maintained at 110 as a minimum elevation, what elevation is it expected to reach at maximum high water, and how is this computed?

(26) With the lake at 110, what area will be overflowed in the lake and river valleys, and what additional area during high lake, and what would be the damage as computed?

(27) What are the proportionate components to be used in the concrete for which estimates have been made?

(28) Frequent reference is made in the canal publications to the engineers and boards of engineers, American and foreign, other than the Bogart Board, who have made reports on the company's plans and estimates. If such reports have been made, can they be furnished?

(29) In replying will you be kind enough to refer to the individual paragraphs by their number?

The information requested is important, as having a direct bearing upon the construction and estimates of cost of the canal, and the Board would be glad to receive it at your early convenience.

Very truly, yours,

William Ludlow, *Chairman.*

Mr. A. G. Menocal,
Chief Engineer, etc., Brooklyn Navy-Yard.

United States Navy-Yard,
New York, September 10, 1895.

Dear Sir: Referring to your letter of August 29, relative to reported discrepancies in the level of the river San Juan at Ochoa, and also to distance of that point from the lake, and other information, I beg to say:

(1) That I have not the report of Childs's survey before me but if I had it I could not attempt to explain discrepancies or errors in the levels given by him.

(2) That the levels given on the plan and in the reports of the Nicaragua Canal Company have been repeatedly checked between the sea level and the river San Juan at Ochoa, and are believed to be correct.

(3) Lull's levels were not checked, yet it appears from his profile that the level of the San Juan at Ochoa, at low water, does not differ materially from that given by the company.

(4) I have been unable to find on pages 76 and 84, of my part of Lull's report, the distances from the lake to Ochoa as given in your letter. The canal company's profile was made from the Government survey of the river and should very nearly coincide with that given by Lull. The distance of 64.50 miles given in the table of distances does not agree with the profile, and is either a printer's error, which by an oversight has been carried forward, or the result of scaling off the distances along the sailing line on the old Government plan, much shrunk by age and exposure. The error might be traced back if desired, but I regard it of no practical importance in considering the practicability and estimated cost of the canal.

(5) The diversion of the upper Deseado may be found necessary during the progress of the excavations in the "divide." If so, it can be done at little cost, and should be paid for by the contractor as part of his work of preparation.

(6) The diversion of the Rio Frio, if found necessary after raising the level to 110 feet (which is regarded as very doubtful), would be an inexpensive work, and in my opinion should not be undertaken until its necessity has been demonstrated by experience.

(7) Plan and estimates for the diversion of the upper Rio Grande, should such work be found necessary, have been forwarded you.

(8) In case a low-level canal is constructed in the valley of Tola, the small stream of that name can be taken into the canal by a weir and discharged into the Rio

Grande just below the Tola. The cost of this weir has been included in the estimate for the canal.

(9) I see no reason why the lower Rio Grande should be prevented from discharging into the upper harbor of Brito.

(10) Estimated cost of the alternative low-level canal for the western division has been sent to you.

Yours, truly,

A. G. MENOCAL,
Civil Engineer, United States Navy.

Col. WILLIAM LUDLOW,
United States Engineers, Chairman Nicaragua Canal Board.

NICARAGUA CANAL BOARD,
Army Building, New York, September 11, 1895.

DEAR SIR. Referring to the recent estimates for the construction of the La Flor Dam and Locks 4 and 5, will you please give the Board information as to the following points:

(1) What provision is to be made for the discharge of the valley drainage during the construction of the dam, including excavation, sheet piling, concrete core wall, etc.?

(2) What is the composition of the masonry walls at the head of Lock 4, which is charged at $10 per cubic yard?

(3) The item for machinery for Locks 4 and 5 is reduced from $150,000 in the 1890 estimate to $100,000 in the 1895 estimate, which is the estimate for each of the single locks. Is the reduction intentional, or does the item need correction?

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

NAVY-YARD, *New York, September 16, 1895.*

DEAR SIR: Referring to your letter of the 11th instant, I beg to answer the questions therein contained, as follows:

(1) No definite plans have yet been adopted for the La Flor Dam, the final solution of the problem being still under consideration, pending more exhaustive investigations of the physical conditions at the site. No provisions for the discharge of the valley drainage during construction of the rock-fill dam, originally estimated for, were regarded necessary, but the deep borings made later show that this system of construction is not well adapted at that point, and the estimates for that work as it now stands should be taken as a rough approximation.

(2) The wall at the head of Lock No. 4 is estimated as rubble, built in cement mortar.

(3) The estimate for machinery for Locks 4 and 5 was intentionally reduced from $150,000 to $100,000, an amount regarded as ample for this case and excessive for the single locks. If a correction is made in the estimate, the latter amount should be reduced, I think, to $80,000 for single locks.

Yours, very truly,

A. G. MENOCAL.

Col. WILLIAM LUDLOW, U. S. A.
Chairman of the Nicaragua Canal Board, New York.

NICARAGUA CANAL BOARD,
Army Building, New York, September 11, 1895.

DEAR SIR: Have you any plans or other data with reference to the system of lighting the navigation which will indicate the position and arrangement of the lights, buoys, etc., included in the estimate?

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

NICARAGUA CANAL BOARD,
Army Building, New York, September 14, 1895.

DEAR MR. BENNETT: Will you be good enough to send the Board the original plan and profile of the Peary survey, and any other data you have in connection with it, including estimates, and if there is a report on the line we would like to have that also.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company,)
54 Broad Street, City.

THE MARITIME CANAL COMPANY OF NICARAGUA,
54 and 56 Broad Street, New York, September 14, 1895.

DEAR SIR: Your letter of this date is received.

You have already a portion of the data of the "Lower" route, and I will get together the remainder as soon as I finish the drawing of the San Carlos sluices, etc.

This data is very much scattered, as the company deemed this route less practicable for its purposes than the other, and therefore did not consider it necessary to embody it in any complete map and profile.

It will be a matter of considerable time to get this data together.

Yours, respectfully,

F. W. BENNETT.

Col. WM. LUDLOW,
Chairman, Nicaragua Canal Board.

NEW YORK, *September 14, 1895.*

DEAR SIR: Referring to your communication of the 10th instant, I beg to transmit herewith the information called for, as follows:

(1) It is believed that a canal 120 feet wide at the bottom will offer greater facilities to the passage of ships traveling in opposite directions than a less bottom width with turn-out at intervals, as the latter system would compel ships to come to a stop at the meeting places. The plan suggested by you would be more economical and might be adopted at the start, having in view the final enlargement of the prism, as has been done at Suez, when the traffic requires it.

(2) The harbor of Greytown has been estimated at a depth of 30 feet, using as a basis for the computations the soundings given and the datum established by Lieutenant Maxwell in his survey of the harbor, which is low water. In this connection it is proper to explain that in the revision of the estimates made in 1890 the amount of excavation computed for 30 feet depth over the whole area was included, but through oversight the text of the original report made in 1888 was not corrected to conform to the depth as increased in the estimate. In the Greytown section of the canal, in the river San Juan, and between Lock No. 6 and Brito Harbor, a depth of 28 feet has been estimated, for the reasons, firstly, that such a depth is regarded as quite sufficient for the traffic, as has been shown by experience in the modern ship canals of the world; and, secondly, because the depths therein can be readily increased to 30 feet later on, if found necessary.

(3) Attached please find a table showing the full depth and widths proposed for the several sections of the navigation from sea to sea, with expression of the datum plane of reference, from which the depths in the several sections are measured.

Table showing the dimensions of the several sections of the proposed canal.

Section of canal.	Length.	Width, top.	Width, bottom.	Depth.	Area of prism.	Datum plane of reference.
	Miles.	*Feet.*	*Feet.*	*Feet.*	*Sq. feet.*	
Greytown to Lock No. 1	9.297	288	120	28.5	....	Mean level of Greytown lagoon, which is 0.271 feet above mean sea level.
Lock No. 1 to Lock No. 2, canal	1.203	210	120	30	4,950	+ 31 feet above mean sea level.
Lock No. 2 to Lock No. 3, canal	.165	210	120	30	4,950	+ 66 feet above mean sea level.
Lock No. 2 to Lock No. 3, basin	4.263	....	....	....	....	Do.
Lock No. 3 to western end of Eastern Divide Cut, canal.	2.917	100	100	20	3,000	+106 feet above mean sea level.
Lock No. 3 to western end of Eastern Divide Cut, Deseado Basin.	.649	....	....	....	....	Do.
Western end of Divide Cut to Ochoa, canal.	1.337	184	80	30	3.673	Do.
Western end of Divide Cut to Ochoa, San Francisco Basin.	11.163	....	....	....	....	Do.
River San Juan to Toro Rapids	37.22	....	....	....	....	The inclined plane between 110 feet at lake and 106 feet at Ochoa.
River San Juan where dredging is needed.	29.25	....	125	28	....	
Lake Nicaragua	....	....	150	....	....	+110 feet above mean sea level.
Lake to Western Divide Cut, canal	1.544	210	120	30	4,950	Do.
Western Divide Cut, canal	4.924	100	100	30	3,000	Do.
Divide Cut to east end of Tola Basin, canal.	2.519	184	80	30	3,673	Do.
East end of Tola Basin to Lock No. 4, basin.	5.455	....	....	....	....	Do.
Lock No. 5 to Lock No. 6, canal	1.591	184	80	30	3,673	+ 25 feet above mean sea level.
Lock No. 6 to harbor of Brito, canal	.570	....	120	28	....	Mean low water.

(4) The depth and width as actually provided for in the estimates, and the datum plane to which the computations are made, are given in the table referred to in answer 3. As the estimates provide for securing the whole depth proposed no addition to the estimates are requisite.

(5) Dredging in the outer harbors at Greytown and Brito has been estimated at 30 feet depth below low water, and no additional deepening is regarded as necessary to provide for the rise and fall of the waves. The entrance channel at Greytown is proposed to be excavated to the 5-fathom curve and the breakwater has been estimated to extend also to that depth, or a distance of about 2,100 feet from the coast line at the time of Maxwell's survey. At Brito the depth at the entrance between pier heads will be about 40 feet. The additional length of pier to the 6-fathom curve has not been estimated for.

(6) The minimum radius of curvature in the canal in excavation is 3,820 feet or 1° 30′ curve. In the river San Juan there is one curve or bend above Castillo with a radius of curvature in the sailing line of 2,250 feet, and others of about 3,000 feet radius. The amount of 422,500 cubic yards estimated above water in river section is intended to provide for cutting off the bends at Castillo and Toro. This estimate is not based on actual cross sections and borings. The quantities are only approximate, but they are believed to be liberal enough to cover all contingencies, should the cutting off of the bends be determined necessary. The necessity is regarded as doubtful.

(7) Temporary terminal and landing facilities at the two harbors and the lake, prior to the completion of the Brito and Greytown entrances, have not been estimated for separately; they, together with shops, etc., form part of the work of installation, and their cost is included in the estimates and should be charged to the various works as part of their cost. For shops, hospitals, etc., provision is made in the large amount allowed for contingencies partly to cover these items of expense and others, which can not be enumerated and described in detail at the present stage of the project. At Brito ships can lie offshore with safety and comfort, and it is believed that good lighters and tugs of light draft, material, machinery, etc., can be brought into the river section at every high tide with little trouble and expense. Considerable mahogany and other lumber has been shipped from that place, and I have the testimony of those engaged in the business that they experienced but little inconvenience. At Greytown the canal company has had experience in the past in landing material under difficulties, but, while comparatively expensive

and inconvenient at times, the system of lighters and tugs employed gave satisfactory results.

(8) No attempt has been made to enter into the details of branch railways, tracks, sidings, etc., required to handle and dump the materials of the two divide cuts. The estimates provide for railroad from Greytown to Ochoa and from the lake to the Pacific, by which materials from the excavations needed for the various works can be distributed along the line, but the temporary sidings and tracks are considered part of the contractors plant and will have to conform to the methods employed by them for doing the work.

(9) The plant and appliances for the construction of the Ochoa Dam will consist in the necessary sidings to receive and dispatch trains, and in cableways, slings, chain nets and boxes, buckets or platforms, etc., to handle the material. The material will consist of large and small rock. The large blocks of stone, weighing from 4 to 10 or more tons to form the main body of the dam, the smaller material to fill the voids, and the whole to make up a closely compacted mass.

The abutments are to be protected against erosion by sheet piles, penetrating into the hills, and below the bed of the river to hard material. Well-rammed concrete will be deposited in trenches between the rows of sheet piles.

To shorten this communication I beg to invite your attention to the following, pages 28, 29, and 30 of my paper presented to the World's Water Congress at Chicago, in which is explained the method proposed for depositing the material during construction of dam.

"The Ochoa and Tola dams are the keys controlling this great problem at the east and west ends of the summit level, and should not be passed without special notice, particularly so the former, in which a novel method of construction is contemplated. This work has been for years the subject of long study and careful consideration. The diversion of the river San Juan is well nigh impossible; and construction by the usual methods, with either cut stone or concrete, of so important a work in opposition to the mighty power of the stream, is a problem involving the most serious difficulties. It was at first proposed to build a stone dam upon a series of arches supported by tiers starting from the foundation, through which the water could flow freely during the construction of the main part of the structure, these openings to be closed by gates in the upper side when the upper part of the dam, its approaches, and aprons, were completed; and then to be filled with masonry from the lower side while the water was rising in the basin.

"This was, perhaps, as a practical solution, probably the best under the circumstances for that style of dam, but its execution would be tedious, difficult, and expensive, and there was to be always present an element of doubt not easy to eliminate as to the final success. The building of the foundations and pilasters for the support of the arches in constant contention with the whole river would be a most difficult undertaking, in which the items of time and cost would remain unknown quantities to its completion. Another idea has since been suggested, which seems to embody simplicity, economy, and safety. It consists in dumping from an aerial suspension conveyor large and small material, properly assorted, across the river from bank to bank until a barrier is created sufficiently high and strong to arrest the flow and hold the water at the required level; the body of the dam to be made up of large blocks of stone, weighing from 1 to 10 tons, and smaller material to fill the voids. Its base will be quite broad as compared with the height, probably from 400 to 500 feet between the foot of the upstream slope and the end of the apron. The top is estimated 30 feet wide, the rock upstream slope 1 to 1, and the apron downstream slope 4 to 1, with the lower portion flattening down to 5 or 6 to 1. On the upstream side small material, such as stone fragments, gravel, clay, etc., selected as circumstances may require, will be deposited, as the work advances, in sufficient quantity to make the dam as tight as wanted. It is not expected or even desirable to have a water-tight structure, the object sought being simply to oppose such an obstruction to the river as may be necessary to hold the water at the required level. The minimum flow of the river is about ten times the water needed for working the canal; consequently, nine-tenths of it can be wasted with advantage. That the dam will eventually become tight there can be no doubt, as the small drifts and detritus forced in by the currents will gradually fill the voids and consolidate the structure.

"The method of construction will be quite simple. After protecting the abutments against possible erosion, large pieces of rock will be dumped in the bed of the stream from three to four cableways spanning the valley. The material should be distributed uniformly over the area under the main portion of the dam, commencing upstream, and keeping up, as nearly as possible, an even level. Scouring will soon cause settling of the blocks into firmer soil, the upper level in the meantime being constantly raised by depositing more stone, while the small material is being forced by the current into the voids, and the overflow dislodging and rearranging the unstable blocks until they reach a final resting place. This process to be continued until the resistance at the bottom becomes so great as to check scouring due to maximum pressure, when the dam will be carried up to the desired level. The river, in the meantime running over the mound, will readjust the material in and adapt the apron to the necessary conditions of stability to withstand the effect of the fall and carry off the water safely. If the dam is then raised so as to shut off a whole or the largest part of the river flow, which can by that time be discharged over the waste weirs, the structure will be permanent.

"If the river is not able to prevent the completion of this work, having, on the contrary, greatly contributed to its construction by a better distribution and consolidation of the material, now that the waters are diverted to another outlet, no fear need be entertained as to injury from that source. There may be some settlement and final readjustment of the component parts for some time after completion, but that can be easily remedied by depositing more material where needed. It is believed that this dam will be safer, as it is by far more economical, than a stone dam. An earthquake may cause serious damage to a masonry dam, but it can do no harm to this. On the contrary, it may add to its consolidation by bringing the parts in closer contact. There are no cemented joints to be opened, and a seismic disturbance would have a tendency to compact rather than to disintegrate the large mass. The rock for the dam will be brought by rail from the divide and delivered immediately under the wire cables, each one of which will be capable of handling and depositing about 1,000 tons in ten hours. Consequently, the work can be completed in from four to five years and, if it need be, in less time."

The stability and permanence of this dam is inherent in the mass and weight and in the great friction or resistance opposed to the flow of water through the mass or under its foundation.

There will necessarily be some modifications in the details of construction during the progress of the work, but it is believed that the plan suggested will meet the requirements.

As regards La Flor Dam, no detailed plan for its construction can be finally decided upon until a more extensive study of the physical conditions at the site have been made and the type and height of dam to be built decided upon. As I had occasion to explain to the Board while on the ground, this matter is still under consideration, and the estimates for the work are only approximate. If the dam is built, it will probably consist of an earth embankment with a concrete core, and, with the exception of some special precautions in the foundations, its plan and method of construction need not differ materially from similar work elsewhere.

(10) The embankments in the San Francisco and other sections of the canal are proposed to be of solid clay, compacted by rolling in layers of from 6 to 9 inches thick, or by other approved engineering methods best adapted to meet the requirements in each case, the site being previously stripped of roots and loose soil and well drained.

In the high embankments all the mud will be removed until the stiff clay bottom is laid bare, the pit being kept dry by pumping, if necessary, and the streams drained through the adjoining sluices. Two rows of tongued and grooved sheet piles, 8 inches thick and 40 feet long, will then be driven in the bottom of the trench between and up the slopes of the abutment hills. The filling will then be started, as described, until it reaches a height of about 20 feet above the bottom, when another row of sheet piles will be driven in the center of the embankment, penetrating about 20 feet below the bottom and extending into the abutting hills, the trench to have a bottom width corresponding to the base of the embankments with the slopes proposed, the triangular sides in the pit to be filled with the same material and by the same methods employed in building the embankments against the natural slopes of the ground, or the bulkhead that may be needed in some cases, to keep off the water and loose soil from the excavations.

The smaller embankments proposed to close gaps in the surrounding ridges will also be built of clay, the ground being previously cleared of roots and loose soil and stepped off, so as to prevent slides and to break joints. I will not occupy your time with a minute description of these low embankments. They need not differ from similar works properly built for similar purposes elsewhere, and call for no special methods in engineering.

The water slopes and the top of the embankments will be paved with hand-packed stone 2 feet thick, and the dry slope will be planted with grass as fast as the material consolidates. No additional precautions, it is believed, are needed to insure the impermeability and maintenance of these structures.

(11) The company has reached no final conclusions with regard to the proposed change in the position of the Chanchos embankments. A new and more favorable location as to foundation and height of embankment has been found some distance up the valley, but work by the company was suspended before the final survey of the site was completed, and no change has yet been made in the plans and estimates.

(12) There has been no change made in the sections for earth cuts between the east divide and Ochoa. The original estimate of 80 feet wide at bottom is still retained.

(13) Fender wales are not regarded as necessary in the rock cuts 100 feet wide.

(14) I can see no reason why a portion of the surplus water should not be discharged over the Ochoa Dam. This, however, is not a necessary condition of the problem, as the dam can be raised above flood level and all the surplus water discharged by the sluices and weirs provided in the estimate.

(15) The omission of the sheet piling, guides, etc., in the revised estimates of 1895 was unintentional and a clerical error. The amount of $65,000 should be added to the estimate on account of it.

(16) The trestles estimated for in 1890 in connection with the San Francisco and Deseado embankments were intended for dumping rock into the rock fills and not earth for the embankments. As all the embankments are now estimated of earth, the trestles are no longer needed. This involves no change in the unit price of earth embankment.

(17) Copy of drawings of the San Carlos sluices will be furnished you as soon as they can be gotten ready.

It is proper to say in this connection, and in reference to your queries (18) and (19) that the company suspended operations and discharged its force of engineers and draftsmen just as the final detailed surveys at the site of dams, locks, embankments, etc., were being completed, the borings at La Flor being the last work done after operations on the canal had been stopped. For these reasons many detail drawings of the work, such as you call for, were not completed, and in some instances not even commenced. To go into the labor and expense of preparing working drawings for such important works before the field of improvement had been exhausted and all necessary data accumulated was regarded as a useless expense.

(18) and (19) Attention invited to (17).

(20) In case of a low-level canal in western division the sections will be as follows: From the lake to Station 449 + 12 the prisms are identical for both the high and low level routes.

From 449 + 12 to the tidal lock the width at bottom is 120 feet with slopes 1½ to 1, except for 1,975 feet below Lock No. 4a, in which the width is 100 feet. No special provision is made for turn-outs. The wide section affords ample space.

(21) The changes contemplated in the positions of locks are, first, for Lock No. 6, near Brito. It is believed that by changing the location up the valley nearer to La Flor, or by diverting the present location of the canal so as to bring the lock close to the foothills of the coast range, more favorable foundations can be obtained than is shown by the last borings taken on the present site. These changes would not alter materially the estimate of canal excavation. Secondly, changes in Locks 4 and 5 contingent on modifications of the plan for the La Flor Dam.

(22) Additional investigations at the site of the La Flor Dam will consist mainly in sinking pits and borings for the purpose of obtaining more extensive information as to the geological formation than acquired by the borings already taken there.

If the dam plan is adhered to, some survey will be needed to locate a diversion channel, tunnel, and sluice for the flow of the Rio Grande during construction, and for better control of the surplus waters afterwards. The diversion of the stream was not regarded necessary in connection with the originally proposed rock-fill dam, a construction not well adapted to the physical conditions shown by the last borings.

The last clause of this question is too broad to admit of an answer in detail. I should say that the company should make additional local surveys, borings, gaugings, etc., at all points where its information concerning what is now proposed is not thoroughly conclusive.

In a work of this magnitude, involving the construction of numerous works of various kinds, and under different conditions, in a new country, there is a vast field for investigation by the engineer, both while planning and during construction, which can not be regarded as exhausted until his work is finished. It is impossible, therefore, to state at the present stage of the enterprise what additional surveys, gaugings, borings, etc., the company proposes along the whole route, nor at what points nor for what special purposes these are to be made.

(23) The area of the lands above the La Flor Dam which would be overflowed by its construction is 4,126 acres. The estimated cost of the damages for the area in excess of the right of way through the basin, already paid for by the company under a stipulation of the concession, is $50,000.

(24) Owing to the constant changes in flows and section of the river, its slope when dammed can not be established with mathematical precision. The slope assumed to determine the elevation of not less than 110 at the lake is mainly based on observations of the fall of the river from the lake to Toro and from Machuca, through the Aguas Muertas, to the confluence of the San Carlos, which in both cases is determined by natural obstacles. From the data thus obtained is mainly estimated the elevation which the obstruction of the dam at Ochoa will produce at the lake.

(25) With the lake maintained at 110 as a minimum elevation, its fluctuations

above that level can be controlled and kept within desired limits. With existing conditions at Toro, which may be regarded as the weir controlling the lake, the lake and river have necessarily to rise considerably in order to create sufficient sectional area to carry off the flow at high water.

These conditions will be greatly modified by the proposed excavations in the lake and river, which will add about 2,000 square feet to the channel at Toro, or about 80 and — per cent, respectively, at low and high water, thereby increasing in the same proportion the lake discharge without a proportional increase of head. But the main controlling element of lake level is to be found on the west side, where about 60 per cent of the difference of the lake discharge between low and high water can be discharged through that section of the canal, with a velocity not exceeding 2 miles an hour in the narrow sections, and by weirs and sluices and through the locks discharged in the lower Rio Grande and through the latter and the canal into the Pacific. It is believed, therefore, that with exercise of sound judgment in the application of these means the lake can be so controlled that its level need not vary more than a foot or two.

(26) No attempt has been made to ascertain what area will be overflowed in the lake and river valleys when the lake is at 110 or above that level. No awards for damages are anticipated.

(27) The proportionate components to be used in the concrete for which estimates have been made will be controlled by the nature of the components and the conditions of the work and of the locality in which the concrete is to be used. If the object is to find the basis for the price given in the estimate, I will say that the average proportionate components will be 1, 2, 5, best Portland cement being used.

(28) The reports made by engineers, American and foreign, other than the Bogart Board, have been made to the parties who employed them and not to the canal company. They are not accessible to the company, and although we have been informed of their favorable character we can not furnish them.

I remain, with much regard, very truly, yours,

A. G. Menocal, *Chief Engineer.*

Col. William Ludlow,
United States Engineers, Chairman Nicaragua Canal Board.

Navy-Yard, *New York, September 16, 1895.*

Dear Sir: Replying to your letter of the 11th instant, relative to the estimate for lighting the navigation, I beg to say that the preliminary arrangements and estimates for lights, buoys, etc., were made by Lieut W. I. Chambers, U. S. N., and that as his work could only be regarded as an approximation, his plans and other data with reference to the system were not retained by the company, and if in existence they are in his possession.

Very truly, yours,

A. G. Menocal.

Col. William Ludlow, Esq.,
Chairman of the Nicaragua Canal Board, New York.

The Maritime Canal Company of Nicaragua,
54 and 56 Broad Street, New York, September 20, 1895.

Dear Sir: Your request, by favor of 14th instant to Mr. F. W. Bennett, has my attention.

Mr. Bennett has made careful search through all the company's maps, etc., and reports that there does not exist any original plan and profile of the lower route, and from such little knowledge as I possess I am entirely sure that none was ever made.

All that he finds pertaining to it are the original field charts and profiles in sections, which Mr. Bennett will hand you herewith. Even these are not continuous, some sections in swamps being omitted. The datum of levels differs in each, and they have not been reduced to sea level, as you will at once perceive.

It appears that after the report made by the board of engineers upon the two routes, of which Mr. Menocal has spoken to you, but which, by the way, I am unable to find, the company considered the lower route so manifestly inferior that they adopted the upper, the route now under consideration, and from that time abandoned further study of the lower route.

Yours, respectfully,

Thos. B. Atkins,
Secretary.

Col. William Ludlow,
Chairman of the Nicaragua Canal Board.

NICARAGUA CANAL BOARD,
Army Building, New York, September 27, 1895.

DEAR MR. BENNETT: In going over the borings for the eastern divide, the original notes for many of these are missing. Will you be kind enough to see if the remainder can be furnished? I am informed also that all of the borings were copied out of the notebooks into a special record book. Will you please see if this can be recovered, and let us have it?

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company),
54 Broad Street, City.

NICARAGUA CANAL BOARD,
Army Building, New York, September 27, 1895.

DEAR SIR: In checking the computation for the lake dredging on the basis of 30 feet depth with the company's cross section, it is found that the quantity exceeds that stated in the estimate of 1890 and 1895 by nearly a million of yards.

The discrepancy may perhaps be accounted for on the supposition that the depth assumed in the company's estimate was 28 feet instead of 30, conforming to the proposed depth in the San Juan River below.

Please let us know if this be the fact, and at what reference above mean sea level or below 110 the bed of the lake channel is provided for.

With much regard, very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

UNITED STATES NAVY-YARD,
New York, September 30, 1895.

DEAR SIR: Replying to your favor of the 27th instant, relative to dredging in the lake, I beg to say that the company's computations were made for a channel extending 72,000 feet into the lake to a depth of 22.6 below lake level at 102.6, or for a depth of 30 feet below 110.

I have not before me the original computation for the dredging required, but I have directed Mr. Bennett to show you the chart of the lake, showing soundings made by Lieutenant Maxwell, and the proposed channel laid thereon; and I trust that a verification of the computations made in your office, based on this data, will show that the discrepancy, as compared with the company's statement, is not so large as it appeared from the first computations.

With much regard, very truly,

A. G. MENOCAL.

Col. WILLIAM LUDLOW,
United States Engineers, Chairman Nicaragua Canal Board.

NICARAGUA CANAL COMPANY,
Army Building, New York, October 1, 1895.

DEAR SIR: The Board is recently in receipt of copies of a pamphlet on the Nicaragua canal by William L. Merry, purporting to be published by authority of the Chamber of Commerce of San Francisco and other responsible bodies.

The description of the canal is evidently obtained from the company's records, and on page 26 the following statement appears:

"The cost of the canal has been very carefully estimated by Engineer Menocal and by two boards of consulting engineers, one in the United States and one in England. Menocal makes a cost of $65,084,176, exclusive of bankers' commissions, discounts on securities, and interest during construction. The English board exceeded this by $600,000, a remarkable concurrence."

Will you be kind enough to give the Board such information as you may have relative to the composition or personnel of the English board of engineers, to whose report reference is made, the nature of its investigations of the canal project, when it was made, and what were the unit prices upon which the board's estimate of $600,000 more or less of excess of the company's estimate was based.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

UNITED STATES NAVY-YARD,
New York, October 2, 1895.

DEAR SIR: Referring to your letter of the 1st instant regarding the statement contained in a pamphlet on the Nicaragua Canal published by William L. Merry, in which he states that the estimated cost of the canal as computed by a board of English engineers exceeds the estimates made by me by $600,000, I can only say, in reply to your inquiries, that in my opinion Mr. Merry refers to the report made by Mr. H. F. Donaldson, chief engineer of the London and East India Dock Company, to the syndicate that employed him to visit Nicaragua and examine the route of the canal, the proposed plans, estimates, etc., and to report his conclusions thereon.

Mr. Donaldson was at the time engineer in charge of a section of the Manchester Ship Canal.

He visited Nicaragua with another engineer of the Manchester Canal Company, Mr. Gooch, associated with him in the investigation in 1891, and inspected the route of the canal, the plans, the work then in progress, etc., spending about one month in the country. Then they went to Costa Rica and examined the location of a railroad in that country in the interest of the same syndicate, after which they came to the United States, visited the Sault Ste. Marie Canal, and spent considerable time in the Nicaragua Canal Company's office in New York examining the plans, records, etc., of the company.

I am not at liberty to say, regarding his report, beyond his unreserved statement to me, and I think to others in London, to the effect that he had fully indorsed the project as proposed in the company's plans, and that his estimate of cost was very close to the one made by me. Whether the difference was $600,000 or £600,000 I am not prepared to state. His report is private property of the syndicate that employed him, and, as far as I know, has not been published.

Very truly, yours,

A. G. MENOCAL.

Col. WILLIAM LUDLOW,
United States Engineers, Chairman Nicaragua Canal Board.

NICARAGUA CANAL COMPANY,
Army Building, New York, October 8, 1895.

DEAR SIR: (1) Referring to paragraph No. 2 on pages 2 and 3 of the final report of 1890, the Board would be glad to have the observations made for determining the currents inside and outside the Greytown and Brito harbors, the direction of the winds and the rise and fall of tides at those points, and the plane of reference to which the soundings are reduced, which is not noted on the charts.

(2) Referring to paragraph No. 3 on page 3, the Board would be glad to have the data of all the local surveys made in the river San Juan, in order to arrive at a close estimate of the amount and cost of excavation, and to determine with some precision the means of constructing dams, etc. As so far furnished, the only data are the Lull survey and the few borings made in the river bed at Ochoa.

(3) It is observed that the estimates for lock construction contained in the report of 1890 are carried forward into the recent estimates for 1895. The locks of 1890 were to be 650 feet long by 70 feet wide, but in the Chicago paper of 1893, it is observed that this width is increased to 80 feet. In view of the fact that the estimates are not changed, will you be kind enough to furnish the Board with detailed estimates for each of the locks, showing quantities and composition of the several materials used and the unit prices employed in the computation of cost?

With much regard, very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. A. G. MENOCAL,
Chief Engineer, etc., Brooklyn Navy-Yard.

NAVY-YARD, *New York, October 10, 1895.*

DEAR SIR: I beg to acknowledge receipt of your letter of the 8th instant, and to say in reply thereto:

(1) I have directed Mr. Bennett to furnish the Board with all the note books containing the information called for in (1) of your letter. The soundings were reduced to the plane of low tide.

(2) Mr. Bennett will also deliver to the Board the note books, sections, and plans of local surveys made by the company in the river San Juan. I would say in this connection that the computations for excavations contained in the company's estimates were based on the Government surveys of the river.

(3) The company has had under consideration for some time an increase of width in the locks from 70 to 80 feet, but no final action has been taken in the matter, and the estimates for 70 feet width, with a length of 650 feet, have been retained. In this connection I beg to refer to previous communications on this subject, in which the Board has been informed that the company is not prepared to submit, at this time, detailed final drawings of locks, and that the composition of the concrete and other materials to be used in the construction will necessarily be controlled by the conditions and circumstances attending each particular case. Consequently, the detailed estimate you ask for now can not be furnished. The estimates contained in the reports were made with that degree of approximation regarded as sufficient in estimating for work at the stage the Nicaragua Canal is now.

With much regard, yours very truly,

A. G. MENOCAL.

Col. WILLIAM LUDLOW,
United States Engineers, Chairman Nicaragua Canal Board.

NICARAGUA CANAL BOARD,
Army Building, New York, October 10, 1895.

DEAR MR. BENNETT: Will you be kind enough to send us any maps you may have showing the location of Hunt's borings at the Chauchos, Nicholson, and San Francisco? I find we have no maps locating the stations named.

Very truly, yours,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company,)
54 Broad Street, City.

NICARAGUA CANAL BOARD,
Army Building, New York, October 14, 1895.

DEAR MR. BENNETT: May I ask you to be good enough to separate the estimate for the canal in excavation, western division, so as to give us the quantities from Station 452+50, from Lajas to Lock No. 7 A?

Very truly,

WILLIAM LUDLOW, *Chairman.*

Mr. F. W. BENNETT,
(Care Maritime Canal Company,)
54 Broad Street, City.

APPENDIX C.

RECORD OF RIVER GAUGINGS FOR VELOCITY AND VOLUME.

River.	Locality.	Date.	Authority.	Area of cross section.	Velocity per second.	Discharge per second.	Remarks.
				Sq. feet.	*Feet.*	*Cubic feet.*	
San Juan	Fort San Carlos	June 5, 1850	O. W. Childs			11,930	Lake Nicaragua at elevation 103.07; low stage.
Do	Immediately above mouth of San Carlos River.	July 15, 1850	do			19,300	Medium stage.
Do	Immediately below mouth of San Carlos River.	do	do			35,747	Do.
Do	Immediately above mouth of Serapiqui River.	Aug. 8, 1850	do			39,526	Do.
Do	Immediately below mouth of Serapiqui River.	do	do			52,792	Do.
Do	Immediately above head of Colorado River.	Aug. 20, 1850	do			54,380	Do.
Colorado		do	do			42,056	Do.
Lower San Juan		do	do			12,324	Do.
							Elevation of Lake Nicaragua Sept. 19, 1850, 105.62.
San Juan	Above Toro Rapids	Apr. 26, 1873	Lull			12,096	Lake Nicaragua at elevation 102.28; low stage.
Do	Below mouth of Poco Sol	Apr. 30, 1873	do			11,390	Do.
Do	Above mouth of Santa Cruz	May 1, 1873	do			11,630	Do.
Do	Below mouth of Santa Cruz	May 2, 1873	do			12,453	Do.
Do	Above Mico Rapids	May 6, 1873	do			12,948	Do.
Do	Above mouth of San Carlos	May 10, 1873	do			13,200	Do.
Do	Above mouth of Serapiqui	May 16, 1873	do			14,572	Do.
Do	Below mouth of Serapiqui	do	do			16,770	Do.
Colorado,		May 19, 1873	do			16,190	Do.
Lower San Juan		May 20, 1873	do			607	Do.
San Juan	Between mouth of San Carlos and Ochoa	May 21-26, 1888.	Canal Co., by J. H. Covode	11,310	3.665	41,451	Medium stage.
Do	Fort San Carlos	May 27, 1895	Nicaragua Canal Board	7,480		9,420	Lake at elevation 101 07. Velocities measured with floats immersed 5 feet; low stage. Coefficient, 0.9.
Do	Below mouth of Sarapiqui	June 20, 1895	do	21,500	3.5	60,200	Using surface velocity; low stage; coefficient, 0.8.
San Carlos	Immediately above mouth	July 15, 1850	O. W. Childs			16,447	Medium stage.
Do		Nov. 20, 1888	Canal Co., by J. F. Le Baron			7,844	
Serapiqui	Immediately above mouth	Aug. 8, 1850	O. W. Childs			13,266	Do.
Danta	300 feet above mouth	Mar. 21, 1888	Canal Co., by J. F. Le Baron	87.5	.4	35	Low stage.
Do	do	July 16, 1888	do	611	1.25	764	High stage.

San Francisco	Below mouth of the Chanchos	Mar. 23, 1888	do	200	.6	174	Using surface velocity; low stage.
Do	Camp San Francisco	June 14, 1895	Nicaragua Canal Board	221	1.7	376	Using surface velocity.
Do	200 feet below Camp San Francisco	do	do	303	1.05	318	Do.
Do	Below mouth of the Chanchos	June 15, 1895	do	515	1.3	669	Do.
Nicholson	Embankment crossing	June 14, 1895	do	100	1.7	170	Do.
Chanchos	do	June 15, 1895	do	209	1.6	334	Do.
Limpio	Just below Camp Carmen	do	do	45	1.3	58	Do.
Do	At Camp Carmen	do	do	34	1.9	65	Do.
Do	Just above the junction with the Lindo	June 16, 1895	do	9	1.8	16	Do.
Lindo	Just above junction with the Limpio	do	do	10.4	1.6	17	Do.
Deseado	Near site of Virginia Dam	June 17, 1895	do	50	3.0	150	Do.
Do	1,500 feet below Camp Menocal	June 18, 1895	do	277	2.3	637	Do.
Do	Near Camp No. 7	do	do	484	1.5	727	Do.
Do	Near Lock No. 1	Dec. 14, 1892	Canal Co., by Boyd Ehle			285	Water surface; elevation 12.28; medium stage.

APPENDIX D.

SUMMARY OF WATER-GAUGE READINGS FOR ELEVATION.

River.	Locality.	From—	To—	Zero of gauge above mean tide.	Highest gauge reading.	Lowest gauge reading.	Range.	Remarks.
San Carlos	At mouth	1888. Aug. 25	1888. Sept. 8		1.2	—0.8	2.0	
Do	At St. Helena Island	Sept. 11	Nov. 12		0.8	—3.2	4.0	
San Juan	Camp Carazo, San Francisco Island	1889. Mar. 18	1889. Mar. 31		—6.75	—7.60		
Do	do	Apr. 1	Apr. 30		—5.30	—7.70		
Do	do	May 1	May 31		—3.00	—7.85		
Do	do	June 1	June 30		—1.80	—5.30		
Do	do	July 1	July 31		+2.10	—5.30	12.85	
Do	do	Aug. 1	Aug. 31		+0.60	—3.50		
Do	do	Sept. 1	Sept. 30		—2.60	—4.50		
Do	do	Oct. 1	Oct. 25		+5.00	—3.70		
Do	do	Dec. 15	Dec. 31		+3.50	1.80		
Do	do	1890. Jan. 1	1890. Jan. 31		+4.60	—1.40		
Do	Ochoa	1888. Jan. 7	1888.	0.00	62.07			
Do	do	Mar. 14		0.00		47.6	14.40	Observed by F. W. B.
Danta	Camp Philomena	Apr. 21	May 26		3.2	—0.4	3.6	
Chanchos	Embankment crossing	May 22	July 21	42.37	7.9	—1.7	9.6	
Deseado	Near Lower Falls, station 890	1889. June 27	1889. Oct. 29		2.5	0.25	2.25	
Do	Near Camp Menocal, station 650	Apr. 26	June 9	16.84	12.7	3.1	9.6	
Do	do	1889. Nov. 7	1890. Jan. 26		16.5	4.6	11.9	
Do	Near Camp Ammen, station 520	Oct. 2	Nov. 7		13.0	3.0	10.0	
Do	South Branch, near station 470	Apr. 9	Apr. 26		6.1	2.0	4.1	
Do	South Branch, near station 420	Apr. 5	Apr. 9					
Do	do	June 10	June 15					
Do	do	June 21	July 1	.78	9.6	—0.2	9.8	
Do	do	July 8	Sept. 12					
Do	do	Sept. 18	Sept. 21					
Do	At mouth of Benard Creek	July 21	Oct. 2		7.35	0.65	6.7	
San Juanilio	Near mouth of Benard Creek	do	do		7.45	0.9	6.55	

APPENDIX E.

RECORD OF RAINFALL OBSERVATIONS.

Month.	Greytown.	Camp No. 4, 9½ miles by railroad line from Atlantic.	Camp Menocal, 13 miles by canal line from Atlantic.	Silico Lake, 9½ miles from Atlantic.	Camp Carazo, on San Juan River, 11 miles below Ochoa.	Remarks.
1887.						
December	17.59					Last 12 days—Maxwell.
1888.						
January	27.94					Entire month—Maxwell.
February	2.78					First 17 days—Maxwell.
July					34.55	Canal company.
August					19.41	
September	19.8				22.51	
October	12.9				15.86	
November					11.02	
December					20.08	
1889.						
March					2.24	Last 19 days.
April					5.13	
May					9.24	
June					7.39	
July					18.35	
August					20.64	
September					11.69	
October					18.11	Eight days missing from record.
1889.						
November	50.70		24.29		15.47	Greytown last 24 days.
December	[a]64.39		51.55		[b]26.59	
1890.						
January	[c]26.80	[d]29.24			27.20	
February	6.36			9.48		
March	5.93			9.06		
April	18.11			22.46		
May	4.93			8.25		
June	41.56	30.04		[e]2.26		
July	52.59	38.51				
August	36.61	26.56				
September	18.29	18.73				
October	24.36	19.01				
November	25.55	18.99				
December	41.65	[f]34.78				
1891.						
January	19.89	(g)				
February	2.66	(g)				
March	1.95	(g)				
April	10.40	(g)				
May	13.78	(g)				
June	26.95	31.57				
July	23.57	20.53				
August	19.49	16.31				
September	14.16					
October	20.21					
November	28.18					
December	32.74					

[a] From London Engineer.
[b] Nine days missing from record.
[c] Actual record said to be twice this amount.
[d] First 26 days.
[e] First 5 days only.
[f] First 27 days.
[g] I do not know why there is no record for these months.—F. P. D.

Record of rainfall observations—Continued.

Month.	Greytown.	Camp No. 4, 9½ miles by railroad line from Atlantic.	Camp Menocal, 18 miles by canal line from Atlantic.	Silico Lake, 9½ miles from Atlantic.	Camp Carazo, on San Juan River, 11 miles below Ochoa.	Remarks.
1892.						
January	28.57	....	....	....	....	
February	11.33	....	....	....	....	
March	4.98	....	....	....	....	
April	18.38	....	....	....	....	
May	50.88	....	....	....	....	In 6 days there was reported a fall of 30 inches.—F. P. D.
June	11.52	....	....	....	....	
July	38.96	....	....	....	....	
August	23.63	....	....	....	....	
September	11.33	....	....	....	....	
October	27.95	....	....	....	....	
November	36.93	....	....	....	....	
December	24.65	....	....	....	....	
1893.						
January	17.70	....	....	....	....	
February	7.53	....	....	....	....	
March	4.93	....	....	....	....	
April	9.99	....	....	....	....	
May	2.77	....	....	....	....	
June	19.70	....	....	....	....	First 21 days.

Total rainfall at Greytown during the year—	*Inches.*
1890	297.74
1891	213.98
1892	289.11
Mean	266.94

LARGE MONTHLY RAINFALLS AT GREYTOWN.

Month.	Inches.	Month.	Inches.
November, 1889 (in 24 days)	50.70	December, 1890	41.65
December, 1889	64.89	December, 1891	32.74
January, 1890	....	May, 1892	50.88
June, 1890	41.56	July, 1892	38.96
July, 1890	52.59	November, 1892	36.93
August, 1890	36.61		

LARGE DAILY RAINFALLS AT GREYTOWN.

Date.	Inches.	Date.	Inches.
July 1, 1890	4.20	May 1, 1892	5.08
July 2, 1890	4.31	May 2, 1892	4.95
July 11, 1890	4.18	May 3, 1892	4.57
July 12, 1890	2.19	May 4, 1892	1.62
July 13, 1890	5.02	May 5, 1892	5.10
July 14, 1890	4.66	May 6, 1892	5.80
July 15, 1890	2.57	May 7, 1892	4.10
September 7, 1890	4.05	May 8, 1892	4.20
October 9, 1890	4.00		
November 5, 1890	4.10		35.42
December 27, 1890	7.65	July 23, 1892	5.30
January 20, 1891	4.35	Do	8.70
April 28, 1891	5.75		
		October 29, 1892	5.78
June 5, 1891	3.83	October 30, 1892	3.50
June 6, 1891	4.95	October 31, 1892	8.02
			17.30
	8.78	November 20, 1892	5.12
June 22, 1891 (9 hours)	4.51	December 5, 1892	8.95
July 18, 1891 (9 hours)	8.17	June 3, 1893	4.00
December 8, 1891	4.05	June 19, 1893	5.00

Record of rainfall observations—Continued.

LARGE DAILY RAINFALLS AT CAMP NO. 4.

Date.	Inches.	Date.	Inches.
July —, 1890	5.25	July 6, 1891	6.70
July 5, 1891	7.70		

LARGE DAILY RAINFALLS AT CAMP CARAZO.

Date.	Inches.	Date.	Inches.
June 27, 1888	4.60	December 19, 1889	2.90
December 4, 1888	4.00	December 28, 1889	3.50
May 21, 1889	2.90	January 22, 1890	3.00
October 20, 1889	3.00		

LARGE DAILY RAINFALLS AT SILICO LAKE.

Date.	Inches.
April —, 1890	7.12

APPENDIX F.

OFFICE OF THE NICARAGUA CANAL BOARD,
New York, August, 1895.

GENTLEMEN: I have the honor to submit the following report of my examinations of the country on the south or right-hand bank of the San Juan River, in the vicinity of the Serapiqui River.

As it will be easier to follow, I will present it in the form of a journal.

Friday, June 21, 1895.—Mr. H. R. Stanford and I left Greytown at 6 a. m. on the steamer *Hollenbeck* and arrived at Maineri's ranch about 4 p. m.

I had arranged with Captain Maineri to furnish men and canoes for the expedition.

The remainder of the afternoon was spent in getting things in readiness for a start in the morning.

Saturday, June 22, 1895.—We left Maineri's at 7 a. m., with eight men and our messing outfit, in two canoes.

We entered the Serapiqui at 10 a. m., and paddled up it one hour, an estimated distance of 2 miles, in a southwesterly direction to the mouth of the Caño Ceiba, which enters from the right bank of the stream. The Ceiba at this point is a stream of about the same volume as the San Francisco at Camp Frisco, it having a discharge of about 350 cubic feet per second. We paddled up the Ceiba two and a quarter hours, a distance of about 5 miles, and pitched camp on the right bank.

For about three-quarters of a mile from its mouth the water of the Ceiba was of a dark wine color, indicating swamps. Above that it was of a clay color, indicating little swamp drainage. All the tributaries between its mouth and our camp are small.

The banks of the stream are of clay and from 10 to 12 feet high. The bottom is a hard clay, running into telpetate. At no point did silico swamp come to the stream.

After landing, we left our men to build a camp, while Mr. Stanford and I started a picket line approximately east by the needle, and went as far as we could and return to camp at night. We covered a distance of about half a mile. In this distance we passed over two small ridges of dry land, 4 to 6 feet in height. The balance of the distance was covered with water from recent rains to a depth of from half a foot to 1½ feet. The bottom all the way was hard clay.

Sunday, June 23, 1895.—It rained a great deal last night. Mr. Stanford and I, with five men, left camp at 7 a. m. We traversed our line of yesterday to the end, and continued on in the same easterly direction, most of the way through suita flats covered with 6 or 8 inches of water. At 9.30 we struck a stream about two-thirds the size of the Ceiba flowing north. This stream I knew to be the Caño Maria, which enters the San Juan River above the head of Paraiso Island.

We estimated the distance from the Caño Ceiba to be 1¼ to 1½ miles. Continuing our line to the east, we followed up the right bank of the Maria a distance of perhaps one-third of a mile. We then entered a nasty swamp with water and mud from 2 to 3 feet in depth.

The timber was mostly gavilan. At 11 a. m. we struck a small hill, 20 to 25 feet in height.

After passing this hill we again entered the swamp, and crossed several small but well-defined brooks flowing to the north.

The character of these brooks would seem to indicate that hills would be found at no great distance to the south. At 12.15 we crossed a brook flowing to the north, and struck a hill about 35 to 40 feet in height extending north and south. We followed this hill to the north about 1,000 feet, and struck a stream about one-third the size of the Ceiba. This stream I knew to be the Caño Tigre, which empties into the San Juan near the Cuellos. As we now had barely time to reach camp at night, we retraced our steps.

Monday, June 24, 1895.—Rained in torrents all night. I estimate that not less than 6 inches of water fell. The Ceiba rose over 6 feet.

I left camp at 7 a. m. in a canoe to examine the Ceiba higher up. Going up the stream about one-third of a mile a large brook entered from the west, and in a distance of about a mile several streams entered from the east, some of them as large as the Limpio at Cape Carmen.

At a distance of about a mile from camp I left the canoe, and cut a picket to the east, passing over three small ridges running north and south, where I came to a swamp with much water. I went back to my canoe, and proceeded up the stream about 1¼ miles from this point, and again started a picket in an easterly direction. I found low ridges running north and south with well-defined valleys and streams between them. Owing to the heavy rains the night before the streams were all so high that they could not be forded, and it was with difficulty that they could be crossed.

The banks of the Ceiba at this point are from 20 to 30 feet above the water.

Mr. Stanford left camp at 7 a. m. to examine the country westward from the camp between the Ceiba and the Serapiqui. He cut a picket a distance of about 2 miles over low hills surrounded by swamps and lagoons.

Judging from the velocity of the current in the Ceiba, I estimate the level of the swamps at our camp to be at least 40 feet above the water in the San Juan at the mouth of the Serapiqui.

Tuesday, June 25, 1895.—As the country in the vicinity of where we quit work on the 23d seemed to offer the best prospect of finding hills, I decided to move camp to the San Juan River or to some point on the Caño Tigre. I left camp at 7.30 with both canoes and all our outfit.

Mr. Stanford and two men went over the line of the 23d to take it up where we left it and cut out to the San Juan River in a northerly direction.

After reaching the San Juan at the point where I expected Mr. Stanford would come, I patrolled the river until dark, but he did not appear. I spent the night at the house of Senor Juan Hernandez.

Wednesday June 26, 1895.—I engaged a son of Mr. Hernandez and another man to go up the Caño Maria on approximately the line Mr. Stanford was to follow, to find him, if possible, and pilot him in.

As the streams were so swollen, I thought it possible Mr. Stanford had not been able to cross the Tigre, and was following down its right bank. I therefore went to its mouth, and attempted to ascend it in a canoe. I found the current so strong that with six paddles we could not make any headway. The Tigre at this point was 100 feet wide, 10 to 12 feet deep, and had a velocity of about 6 miles an hour. I therefore left the canoe, and started up the south or right bank of the stream. Much of the way the water was over the flats, and whenever any side drainages came in they were from 4 to 8 feet in depth. At a point a little over a mile from the mouth I struck a hill 30 to 50 feet in height bearing off in a southeast direction. Just above was Suita Flat, covered with water from 3 to 5 feet in depth. In several places we had to swim to cross the deeper parts. I continued this reconnoissance as far as I could and get back to Hernandez's house at night, but did not strike any more hills, nor did I reach the hill where I quit work on the 23d.

On arriving at Hernandez I found Mr. Stanford, who had been brought in about half past 9 in the morning by a young man whom I sent to look for him. The distance which he had to travel proved to be greater than we had estimated, and progress through the swamp was slow owing to the high water. In many places the water was too deep to be waded.

Mr. Stanford reports finding hills 50 to 150 feet in height at short intervals all the way through. These appear to be isolated hills surrounded by silico swamps.

Thursday, June 27, 1895.—Moved to a vacant house about 2 miles below the Serapiqui.

At a point about 3 miles below the Serapiqui there is a high hill on the north bank of the San Juan River. This hill is separated from a range of hills which runs off to the north by a swamp about 400 feet wide. Mr. Stanford and I followed this range of hills out some distance. Most of the way it is 150 feet or more in height.

In 1888 I examined this country and made a survey of a line down the Rio Negro, which lies to the north of the San Juan and flows east into the San Juanillo.

At that time I followed the ridges out much farther than we are now able to. The topography, as shown on the map which will accompany this report, indicates a stream rising in the swamp near the San Juan River to the west of this hill and running north into the Negro. This stream was never traced out, but was assumed to go as shown in dotted lines. I am inclined to think that it flows to the north, and then doubles and flows west and south into the small lake shown on the map, and finally into the San Juan River.

Friday, June 28, 1895.—Started a picket line from a point opposite the hill examined yesterday, on a course south 10° west magnetic. For about one-fourth of a mile this was over good hard ground, 15 to 20 feet above the river. We then dropped into a silico swamp, with water from 2 to 4 feet deep. At one time I put down a palm stem to a depth of 20 feet in the mud. We passed through one-half a mile of this to a small hill about 20 feet high lying east and west. After crossing this we entered a sacate swamp, with water too deep to pass. We tried to follow a recent trail through to the Tigre, but found the water over our heads, and were forced to turn back.

A more extended examination of the silico swamp might show other ridges of hard land and a more favorable crossing.

Saturday, June 29, 1895.—We went by canoe to the mouth of the Tigre, and found the water had fallen about a foot. After a hard struggle we succeeded in getting up to a point which we identified as the spot where we ended our line yesterday. I should judge it to be not over 500 or 600 feet from the bank of the Tigre, and nearly in a direction to hit the hill on the south bank. We went up to the point of the hill, where we left our canoe, and followed the hill in a southeasterly direction about a mile, when it ended in a swamp. We came back to where there appeared to be a spur putting off to the southwest. We followed this until we came to a place where the swamp to the westward was only about 200 feet wide, and crossed to another hill 150 feet in height, which we followed for half a mile or more.

When we ended, we were at swamp level, but I think at an elevation above the flowage line of a dam to raise the water so as to give slack water to Ochoa.

These hills are very irregular in shape, and it would be necessary to follow out every spur to say that they were not continuous, but I think the swamps between them are at an elevation sufficient to render hills unnecessary at this point.

Owing to the excessive rains and the extreme high water, it was impossible to do any instrumental work, and explorations were rendered well-nigh impossible where there was any swamp.

Sunday, June 30, 1895.—Made a cross section of the San Juan River at a point from which we started our line on the 28th. The river at this point is 1,550 feet wide, and had a surface velocity of 3.5 feet per second.

Beginning at the south side, the first third of the distance has a depth of 9 feet, the middle third 12 feet, and the north third 20 feet. At this time it was passing approximately 60,000 cubic feet per second.

After making this cross section we returned to Greytown.

I desire to supplement this by saying that in the year 1889 I made an examination of the country immediately south of the Serapiqui Hills. At that time I started from the river at a point which would carry me over the high hills on the south side below the Serapiqui in a southerly direction. After following the hill for nearly a mile I came down to swamp. I then traced the foot of the hill around to the San Juan on the east, and to the Serapiqui on the west. I then continued my original line to the south, across a suita flat, to a hill about 20 or 25 feet in height. This I traced into the swamp at the east end, and to the Serapiqui at the west. I then went up the Ceiba some distance, and found the point of a low hill which I ran into swamp in all directions. From this hill I went across a silico swamp to another hill about 100 feet in height. Following this in a southwest direction, it ended near the Ceiba.

I then went back to the Caño Maria, which enters the San Juan from the south and below the Serapiqui Hills. I went up this some distance and started a picket in a westerly direction, which passed over a low hill and down to the swamp. I followed the swamp to the Caño Ceiba. Returning I followed the swamp all the way from the Ceiba to the Maria.

At the time of this reconnoissance it was with a view to raising the water of the river to the level of not less than 80 feet above tide. I did not deem this practicable, and made a report to this effect.

This reconnoissance, together with my former one, would seem to show that a careful survey of the country south of the San Juan River ought to be made before any definite location of the canal is decided upon.

The map which accompanies this will show at least two sites for a dam well worthy of a more careful study.

In connection with this, I will add that in the early part of 1893 I sent Mr. Boyd Ehle to make an examination of the south bank of the San Juan in the vicinity of Tamborgrande.

He started in at a point some 4 miles above Tamborgrande and found a range of hills about a mile or a mile and a half back from the river. He followed this range down the river until it finally faded out into isolated hills, with suita flats between.

He finally crossed from these hills to the hill at Tamborgrande. These were separated by a narrow lagoon. I requested permission from the general manager to have a compass survey made of these hills, but was not allowed to have it done on account of lack of funds.

Very respectfully,

FRANK P. DAVIS.

The NICARAGUA CANAL BOARD.

APPENDIX G.

TABLE OF UNIT PRICES USED IN FORMER ESTIMATES.

	Childs.		Lull, 1874.[a]	Menocal, 1885.[b]	Canal company.	
	Nicaragua, 1852.	New York, 1852.			1890.	1895.
GREYTOWN HARBOR.						
Stone in breakwater	$5.00 6.00	$3.00	$5.00	$1.50	$1.50	[c]$1.50
Dredging and excavation	.80 1.00	.20 .30	.30	.25	.20	.15
CANAL.						
Dredging				.20	.20	.15
Earth excavation	.25 .30-1.00	.15-.25	.85	.40	.40	.40
Earth embankment	.25	.12	.10			
Rock excavation	1.50	.70	1.50 1.25			
LOCKS AND DAMS.						
Rock excavation	1.50	.70	1.50 1.25	2.00 [d]5.00		
Earth excavation	1.00 .45 .35 .25	.50 .20 .16 .12	.25 .35 .40	.40	.40	.40
Gravel excavation			1.00 2.00			
Mud excavation	.25	.10				1.00
Earth embankment	.25 .30	.12			.30	.30
Stone, gravel, and clay embankment	1.00	.50	1.00			
Hydraulic concrete	8.00 7.00	4.50 4.00	12.00 8.00	6.00	6.00	6.00
Dressed stone	12.00 15.00 16.50	6.75	18.00			
Rubble masonry	6.00 7.00	4.00	9.00			
Dry stone wall			4.00			
Puddle	.20	.10	.75	.75		
Rock fill					.40	
DIVIDE.						
Rock excavation				1.50	1.50	1.25
Earth excavation				.40	.40	.40
Fender wales ... per foot					4.00	
SAN FRANCISCO BASIN.						
Rock excavation				1.50 [e]5.00	1.50	1.50
Earth excavation				.40	.40	.40
Earth embankment				[f].50	.30	.30
Rock fill					.40	
Surface-soil excavation				.30	.50	.40
Mud excavation						1.00
Concrete						6.00
OCHOA DAM.						
Rock fill				(g)	.50	.50
Earth, etc., fill				.50	.25	.25
Stone and gravel fill				2.00 .50		
Earth, etc., excavation				2.00 .30	.40	1.00
Concrete				8.00 9.00	[h]10.00	[h]10.00

[a] The 1874 prices assume cost not greater than in the United States. (See p. 81 of Lull's report.)
[b] The 1885 prices assume greater cost than in the United States. (See p. 39 of report.)
[c] In 1874 stone for breakwater was to come from Monkey Point; in 1885, from Divide.
[d] Tunnel. No dams in east division in 1885.
[e] Tunnel.
[f] Clay embankment in 1885 to be rammed in 9-inch layers.
[g] The Ochoa Dam in 1885 to be of concrete, with earth. stone, gravel, etc., backing.
[h] Concrete in 1890–1895 for abutments.

NOTE.—Columns 2 and 3 represent Childs's prices in Nicaragua and New York, respectively. (See his reports.)

Table of unit prices used in former estimates—Continued.

	Childs.		Lull, 1874. *a*	Menocal, 1885. *b*	Canal company.	
	Nicaragua, 1852.	New York, 1852.			1890.	1895.
SAN CARLOS.						
Earth excavation			*c*$0.35		$0.50	$0.50
Earth embankment					.70	.40
Concrete						6.00
SAN JUAN RIVER.						
Rock under water	$5.00 2.50	$2.00 1.00	5.00	$5.00	5.00	3.00
Earth under water	.60	.20		.40		
Gravel, sand, etc., under water	1.00	.50	.40		.30	.25
Earth excavation above water				.40	.40	.40
LAKE.						
Rock under water			5.00	(*d*)	5.00	3.00
Gravel dredging	1.00	.35	2.00			
Mud, etc., dredging	.50	.20	.20	.40	.20	.20
Stone filling in cribs	2.00	1.00				
LAKE TO BRITO.						
Rock excavation	1.00 1.50 2.50	.70 .75 1.25	1.50 1.25	1.50	1.25	1.00
Earth excavation	.25-.60	.13-.25	.35	.40	.40	.35
Earth embankment			.10			
DIVERSION OF LAJAS, ETC.						
Rock excavation	1.50	.95	1.50	1.50	1.25	1.25
Earth excavation	.25	.12	.30 .40	.40	.40	.40
LA FLOR DAM.						
Surface-soil excavation					.40	.40
Earth and gravel fill					.20	.20
Rock fill					.20	.50
Concrete						6.00
LOCKS.						
Rock excavation			1.50 1.25	2.00	1.25	1.00 *e*1.25
Earth embankment	.30	.12				
Earth excavation	.35	.15	.40	.40	.40	.40
Concrete	8.00	4.00	7.00 8.00	6.00	6.00	6.00
Rubble masonry	7.50	4.00			*f*10.00	*f*10.00
BRITO HARBOR.						
Dredging	1.50	.40	.35	.20	.20	.20
Earth excavation	1.00	.30	.35	.20	.20	.20
Stone in breakwater	3.00	1.25	4.00	1.50	1.50	1.50
Minimum depth of navigation .... feet	17	17	26	26	28	28

a The 1874 prices assume cost not greater than in the United States. (See p. 81 of Lull's report.)

b The 1885 prices assume greater cost than in the United States. (See p. 39 of report.)

c For diversion.

d No rock in 1885. All dredging is at 40 cents.

e Lock 6.

f Above Lock 4.

APPENDIX H.

NOTES ON VOLCANOES AND EARTHQUAKES IN COSTA RICA.

(For the United States Nicaragua Canal Board.)

I.—ACTIVE VOLCANOES OF COSTA RICA.

Although the whole of the main mountain range which runs from the shores of the Lake of Nicaragua to the southern boundary of Costa Rica is probably of igneous origin, it may be asserted that the volcanic phenomena are in their latest period of activity, as seems to be generally the case all throughout Central America. Instead of the twenty volcanoes given for Costa Rica by Montessus de Ballore in his work, "Tremblements de terre et éruptions volcaniques au Centrale-Amérique" (Dijon, Eugène Tobard, 1888), there are in reality only four peaks or small mountain groups still showing signs of activity, viz, Miravalles, Poas, Irazú, and Turialba. There is not a single active crater south of a line going along the railway and main road from Limon to Puntarenas. I do not know of any record of an eruption of the Miravalles since the times prior to the Conquista. The Poas is a geyser subject to great variations in the intensity of its manifestations. The last eruption of Irazú, which took place in 1888–89, was altogether insignificant.

Turialba is probably the most recent and most lively of our fire mountains. From May, 1864, to the end of February, 1866, it kept throwing at intervals an enormous amount of cinders or volcanic sand, which was carried as far as the Pacific Coast by the trade wind. When I visited Turialba, in 1879, I only found a large chimney opened in the wall of an old crater, and through which escaped continuously a hissing column of sulphurous steam. But all through the surrounding region there were scattered evidences of far more active phenomena.

Since the foundation of our meteorological observatory, good series of seismic observations have been taken at San Jose, and it is well to note here that, according to them, most of the shocks seem to be propagated in an undulatory way, and in such a direction as to allow it to be supposed that they derive their origin in the volcanoes of Poas and Irazú. However, in the actual state of our knowledge concerning the Costa Rican seismology, it would not be prudent to draw any positive conclusion as to that point.

As to the geological age of our volcanoes, it can be asserted that the more ancient among them are posterior to the middle of the secondary period and that their greater activity took place posterior to the Pliocene epoch.

II.—LIST OF THE EARTHQUAKES RECORDED IN COSTA RICA.

In relation to its completeness this list may be divided into three groups: First, great earthquakes from 1723 to 1865, registered by chroniclers on account of the havoc they caused; second, series of F. Maison and G. Molina, including all sensible shakes felt in San Jose from 1866 to 1887; and third, series of the Instituto fisico-geográfico-nacional, including all macro and micro seismic shocks registered automatically by means of the Ewing pendulum seismograph from 1888 to this day.

To a superficial observer it would appear that the number of earthquakes has been increasing at a rapid rate from 1723 up to the present date. But it is evident that the increase is simply the consequence of more attention having been gradually paid to the study of seismic phenomena. It is also unnecessary to add that the three groups are not comparable.

GREAT EARTHQUAKES FROM 1723 TO 1865.

1723—May.—Strong eruption of the volcano Irazú or Turialba, accompanied by violent and repeated earthquakes. (Diego de la Haya, Informe.)

1726—May.—Violent eruption of the volcano Irazú, with earthquakes all around. (Off. doc.)

1756—July 14.—Between 2 and 3 p. m. Terremoto de San Bueneventura. Several very severe shocks, lasting about four minutes. (Fco. M. Iglesias.)

1803.—According to G. Molina, a strong earthquake was felt in that year, which damaged Cartago considerably.

1822—May 7.—Terremoto de San Estanislao. Strong earthquake in San Jose at a time when Irazú showed signs of unusual activity.

1835—January 20–23.—Severe earthquakes felt all over Central America and simultaneous with the eruption of the Coseguina volcano in Nicaragua.

1841—September 2.—At about 6.15 a. m. a violent earthquake was felt which destroyed completely the old city of Cartago and badly damaged part of Tres Rios and San Jose. This shock was the strongest of a long period of seismic disturbances, which began about two months before and continued afterwards for several weeks.

1847—May 18.—Eruption of Irazú, simultaneous with strong earthquakes felt from Panama to Rivas de Nicaragua. (Off. doc.)

1851—March 18.—At about 7.15 a. m. a disastrous earthquake caused again the ruin of Cartago, and was felt with less intensity in San Jose, Barba Alajuela, and in the Guanacaste region. The shocks were undulatory and their direction at Cartago was from north to south. Several other shocks were felt during the following days. (Off. doc.)

1853—October 8.—At 12.30 p. m., strong earthquake in San Jose; felt also in Guanacaste, where it damaged the villages of Las Canas and Bagaces. In San Jose the wave path was directed from north northwest to south southeast. (Off. doc.)

1854—August 4.—At 10 p. m., very strong earthquake in the central plateau. Much damage in San Jose and Cartago. According to the chroniclers of the time the movements were succusatori (trepidatory) and lasted for about two minutes.

1860.—According to G. Molina a severe earthquake was felt at some time during that year, but that observer, generally very accurate in his notes, does not give any details.

Series of Francisco Maison and Gullermo Molina, 1866–1887.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1866		2			8	1	1		3		1		16
1867		1	5			1			4	2	2		15
1868	4	1		3	3				2			1	14
1869	4	2	1		7	4	2	3		2	1		26
1870	1					1	1				1		4
1871	3			3	1	3	4	2	1	2		1	20
1872	5		1	2	3	4			1			3	19
1873				2	2	1	3	2	3	3	4		20
1874		1	4				3	1	1			1	11
1875		4	1	1	3	1	2	2	1	2			17
1876	3	3	1	1	5				3	2	2	2	22
1877	1	1	1	2	3			1	3	1			13
1878	2		2	1	1	2	1	7	4	2	4	1	27
1879		6	2	4	8	9	2		1		1	1	34
1880	2		2	2	3	1	1					1	12
1881	1	1				4		2		1			9
1882	3		19	2	1					1	2	1	29
1883	1	2	1								1	1	6
1884				1		1	1						3
1885	3	1		1	4	1				1	1		12
1886			1	1			2				2		6
1887	1	1	2		2		1				1	1	9
Mean	1.55	1.18	1.96	1.18	2.45	1.55	1.09	0.91	1.23	0.86	1.04	0.63	15.64

In this period of twenty-two years the frequency and distribution through the year of the earthquakes were very variable and the intensity of the motion never was of an alarming character but once, the 3d of March, 1882. On that day at 7.48 and 12 a. m. several violent shocks were felt in San Jose, Alajuela, Grecia, Heredia, and Cartago, causing a little damage. The first shock was also observed at Puntarenas at 8 a. m. exactly; another occurred at this last place at 11.30 a. m. of the same day, and a third at 4.30 a. m. on the following day, just at the time of high water. We have no indications as to the directions followed by the seismic waves in the earthquakes of that period.

I took every pains to find an instance of shocks having been felt at Limon or in the settlements along the Sarapiqui and San Carlos rivers during that period, but persons of sound judgment and perfect honesty, most of them foreigners, who lived for years in those places, could not refer to even a single case. Therefore I consider it a safe conclusion to say that the seismic disturbances were almost invariably limited to the Cordillera and its immediate vicinity.

Nicaragua does not seem to have experienced particularly severe earthquakes during those same years, extending from 1866 to 1887. At least, only a few scattered indications of no special gravity are found. The Ometepe volcano had eruptions in May and June, 1883, but I do not find any mention of simultaneous earthquakes in its neighborhood. In June and July, 1894, strong shocks were reported at Managua. On the 1st of October of the same year, several others at Rivas and San Juan del Sur. In October, 1885, a severe earthquake was felt at Leon and Chinendega, which caused considerable material damage. In May, 1886, there was an eruption of the Momotombo, with strong shocks at Managua.

The center of seismic activity during that period of time seems to have been in Salvador, where they experienced disastrous and well-known earthquakes in 1866, 1869, 1870, 1879–80, and 1884–85.

Series of the Instituto fisico-geográfico-nacional de Costa Rica, 1888–1895.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1888	1	1	6	......	......	......	1	......	1	8	5	18	36
1889	13	5	2	......	4	4	3	4	11	9	4	2	43
1890	5	3	3	7	8	5	7	......	1	1	5	4	46
1891	5	3	7	12	9	4	5	7	9	1	12	15	89
1892	5	5	5	8	8	1	2	1	3	......	......	4	37
1893	6	3	6	3	......	4	1	4	......	......	5	8	40
1894	1	2	5	6	1	2	......	4	......	7	1	13	42
1895 *a*	13	10	12	9	......	8	7	8	4	7	(?)	(?)	......

a Up to October 20.

Of these earthquakes only those which began about the middle of October, 1888, and lasted up the 18th of February, 1889, reaching their maximum intensity during the night between 29th and 30th of December, 1888, were of a dangerous character. If we class them all according to the generally accepted scale of intensity of Rossi-Forel, in which the minor shocks correspond to factor I and the strongest to X, we see that the great majority does not pass over IV, which means "a light shock, sensible for man, and producing slight movements of the doors, windows, small pieces of furniture, and other minute objects."

As to their origin, that is to to say, to the point of the horizon whence they come for an observer placed at San Jose, the same series may be classed in the following way:

Year.	Doubtful.	N.	NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.	S.	SSW.	SW.	WSW.	W.	WNW.	NW.	NNW.	Sum.
1888	23	2	....	1	....	....	....	....	....	....	....	....	....	8	....	2	....	36
1889	5	5	1	9	1	5	1	....	....	....	....	....	....	3	....	12	1	43
1890	12	6	....	2	....	3	....	....	....	....	....	....	....	5	6	8	4	46
1891	25	9	3	4	....	....	....	....	....	....	....	....	....	3	9	31	5	89
1892	7	2	....	....	2	2	....	....	....	....	....	....	....	2	1	14	7	37
1893	6	....	2	1	....	....	....	....	....	....	....	....	....	....	3	26	2	40
1894	19	1	9	1	....	1	....	....	....	....	....	....	....	....	1	1	9	42
1895	13	2	6	31	....	1	....	....	....	....	....	....	....	....	1	11	2	67
Sum	110	27	21	49	3	12	1	....	....	....	....	....	....	21	21	105	30	400

Most of the shocks inscribed in the column "Doubtful" were microseisms of indeterminable elements.

The main conclusion to be drawn from this last table is that all our earthquakes, without exception, have their origin somewhere north of San Jose. The great frequency of the shocks coming from the northwest and northeast quarters seems to point to the volcanoes Poas and Irazú, respectively, as the centers wherefrom these earthquakes are propagated.

We possess but a few data concerning the extension of the area of each earthquake, but it can be considered as a certain fact that the isoseismic curves never reach to a great distance from their epicentrum, or, in other words, from the main cordillera where this may be invariably localized. Of the 400 shocks under consideration, only one, that of 4.20 a. m. of December 30, 1888, was felt at Limon and Greytown, and at both places it was almost imperceptible.

Another fact proves the limited extension of seismic areas in this region and the extreme localization of the shocks. In the list I have at hand there are many earthquakes noticed at Puntarenas, Esperza, or in Guanacaste which were not felt at San Jose. Even at Cartago, at about 14 miles from the last-named city, they have often slight shocks which are not perceived here.

Finally, if I had to draw any conclusions out of the facts I have been able to gather concerning the seismic phenomena along the line of the projected canal of Nicaragua, I would do it in the following form:

First. The epicentra of the Central American earthquakes are situated most generally in or near the active volcanoes of the main cordillera or its prolongations. The wave paths never reach to a great distance from their origin and the intensity of the motion is very seldom of an alarming character.

Second. Owing to its great distance from the main cordillera, the eastern division of the projected canal would be safe from any serious accident as far as ordinary earthquakes are concerned.

Third. The western division, situated in the proximity of active centers, as Ometepe and Mombacho, would be less safe, and provision should be made in order to secure the strength of the walls against occasional slides and to prevent any distortion prejudicial to the good working of the locks. I do not know whether there is any canal built for the purpose of navigation in the neighborhood of Charleston, but if it were so, a practical study of the effects of earthquakes on such kind of works ought to be made by its means previous to the drawing of any definitive conclusion.

Considered by themselves only, earthquakes can not, in my opinion, be taken as a serious obstacle to the building of canals or railways in these countries. But it is not so when they occur in connection with the copious rains which characterize our climate. In itself, the rain is a dangerous element, which penetrates the soil, loosens the clay or argillaceous strata, and very often produces considerable landslides. The soil may be soaked with water without giving way, but a sudden seismic shock can easily bring on a catastrophe. However, the general topography of the zone crossed by the western division of the canal, as far as my knowledge of the region allows me to state, does not seem to admit the possibility of easy movements of the superficial strata, and, moreover, the rain is much less in the Isthmus between Lake Nicaragua and the Pacific Ocean than on the eastern slope, as may easily be seen in the last paper of Professor Harrington on "Central American Rainfall."

San Jose de Costa Rica, October 20, 1895.

H. Pittier.

APPENDIX I.

REPORT ON FINAL LOCATION OF THE CANAL.

By A. G. MENOCAL, Chief Engineer.

NEW YORK, *January 31, 1889.*

To the President and Board of Directors of the Nicaragua Canal Construction Company.

GENTLEMEN: I have the honor to submit the following report of the results of the final surveys for the location of the canal through the territory of the Republic of Nicaragua and in that of Costa Rica by the Nicaragua Canal Construction Company under contract with, and on account of, the Nicaragua Canal Association.

These surveys were commenced in the early part of the month of December, 1887, and were conducted with marked ability and uniform devotion to duty by eight well-equipped parties, supplemented by a well-organized and efficient medical department, and the necessary force of draftsmen, artists, clerks, stenographers, and other subordinate assistants.

The eight parties comprising the regular field working force were divided as follows:

Six land surveying parties, each composed of one engineer in charge, four assistants, and from fifteen to twenty laborers.

One hydrographic party, with one engineer in charge, three assistants, and ten men.

One boring party in charge of an engineer, with ten laborers.

In addition to this permanent force, two or three smaller parties, each composed of one or two engineers and a sufficient number of assistants and laborers, were constantly employed in carrying out local surveys, and reconnoissances, either in advance of the locating force or supplementing the location by local detailed surveys at places where additional information was regarded as necessary for a more perfect knowledge of the complicated topography.

This large and efficient force was kept constantly employed from the 15th of December until the latter part of June, when the advanced state of the work made necessary a reduction in the number of employees. In fact, at this time the canal had been located from the Atlantic to the Pacific, and but little information, and this not essential to the solution of the problem, but desirable only in order to arrive at the degree of accuracy prescribed by the company, remained to be obtained. Some of the engineers were then ordered to the company's office, in New York, to be engaged in plotting and developing in a comprehensive and concise form the results of the field operations. The field working force was reduced to three surveying parties and the boring party, which force has been actively at work, and is still engaged in making local surveys, cross-sectioning in the vicinity of the canal work, locating the flowage line in the San Francisco Basin and in the valley of the river San Carlos, and surveying for a canal between lakes Managua and Nicaragua.

The work accomplished to the present time may be summed up as follows:

First. Location of the canal from the Pacific to Lake Nicaragua, with numerous cross-sections, and the survey of the flowage line in the proposed basin in the valleys of the rivers Grande and Tola. Through these valleys two locations have been made, one for a canal in excavation throughout, and the other for a canal partly through a deep basin. Both have been located with the same care and attention to detail. The estimate submitted with this report is based on the latter plan.

The proposed flooded area contains over 4,000 acres of grazing land, and the relative cost of the two methods of canalization can only be ascertained after this land has been legally condemned. Borings having been made at numerous points along the route, including the basin, the curves having been actually located on the ground and detailed surveys for artificial drains, embankments, and weirs, and of the sites of the locks, etc., having been elaborated for both plans, there need be no delay in the progress of the work when a final decision is reached.

Second. The hydrographic party has completed the survey of the harbor of Brito, of the west coast of Lake Nicaragua in the vicinity of the mouth of the river Lajas, of the east coast of the lake at Fort San Carlos, several local surveys in the river San Juan, and the survey of Greytown and adjacent coast and lagoons. These surveys have been carried out with remarkable skill and accuracy and very much in detail. In the lake the soundings have been carried out beyond the 40-foot contour, and off shore at Brito and Greytown to the 9-fathom line. In the inner harbors and in the rivers in the vicinity thereof the exact contour of the bottom can be determined by the numerous soundings taken. Observations for determining the currents, both inside and outside the harbors, for the direction of the winds and for the rise and fall of the tide have also been taken. All this comprises a mass of most valuable data, which has been used to great advantage in designing the necessary work for the improvement of the harbors and in estimating the amount and cost of the dredging required therein.

Third. Local surveys have been made in the river San Juan at all places where the data on hand were deemed insufficient for a close estimate of the amount and cost of excavation needed, or to determine with reasonable precision the difficulties likely to be encountered in the construction of dams, embankments, or other works entering as important factors in the general scheme.

Fourth. The river San Carlos has been surveyed from its confluence with the San Juan to a point about 3 miles above its tributary, "Tres Amigos," where the contour, 106 feet above sea level, was reached. From that point this 106 feet contour has been instrumentally located east of the main river and up both banks of all its tributaries coming from that side, following all the sinuosities in the expansions and contractions of the valley until Ochoa was reached, at the south abutment of the proposed dam across the river San Juan, thus establishing beyond a doubt the practicability, at a comparatively small cost, of impounding the waters of the San Carlos at the elevation of 106 feet above sea level, as raised by the proposed dam at Ochoa.

Fifth. The survey of that region from the valley of the Machado, above the site of the dam at Ochoa, to Greytown, has been the subject of much labor and serious consideration, and has consumed much time, and not less than four-fifths of the labor of the expedition. The primeval condition of the country, covered as it is with dense vegetation and high forest growth, through which no extended view can be obtained from any point, of itself renders an accurate knowledge of its topographical features, both laborious and difficult to obtain; but, if I add to this the absolute want of means of communication, except by canoe through capricious water courses, of which but little information has been acquired by previous explorations, and an unusually complicated topography, in which extensive swamps and more or less connected ranges of hills are constantly met with in such an irregular and unexpected manner as to baffle completely all calculation as to its actual condition without an instrumental examination of every inch of the ground, some idea may be gathered of the difficulties with which we have been confronted.

Two routes through the last-mentioned region had been proposed by previous surveys, and it was the object of the association to make a thorough examination of the entire area, so as to eliminate all doubtful questions, and with a perfect knowledge of all the conditions involved to select that route presenting the greatest facilities for the construction of the canal, both in regard to the economy and permanency of the work.

One of the routes extends on a nearly direct line from Ochoa to Greytown, and has been designated the "Upper Route" by reason of its being located in the upper part of the valley and its most striking feature of retaining and extending the summit level to within a short distance of Greytown itself.

The other is known as the "Lower Route," since it descends to the valley level of the San Juan a short distance below Ochoa, stretches along, and at several points runs in close proximity to the bank of the river, until it reaches Punta Petaca, above the San Juanillo, where it turns to the north, and by a straight line reaches Greytown at about the same point as the "Upper Route." This route was located by the United States Surveying Expedition of 1872–73, and the former was the result of my surveys of 1885, conducted by order of the same Government. The work of relocation was undertaken for both routes from end to end with the whole force of the expedition, previous explorations and surveys being ignored except for the information to be derived therefrom and for purposes of comparison, the object being to improve, if possible, on what had already been done. It required the constant labors of six surveying parties, and the boring party six months, before the location of the two routes had been elaborated and advanced to the point where a fair comparison of their relative merits could be made; and, since the selection of the "Upper Route," two parties have been engaged for five months in perfecting the location and gathering such a mass of valuable information as to leave no doubt whatever regarding its superiority, and the amount and character of all the work involved in the construction of the canal. No problem has been left unsolved, and what is now presented as the result of these arduous labors is an actual representation of the natural conditions.

THE PROPOSED ROUTE.

The proposed route from the Atlantic to the Pacific is in general direction and, with but slight modifications, identically the same as that proposed by me in 1885. The changes introduced consist principally in the addition of two new basins and the extension of free navigation in the San Francisco Basin, by which the length of canal in excavation has been considerably reduced, with proportionally increased facilities to navigation, and the problem of draining the country traversed by the canal satisfactorily solved.

San Juan del Norte (Greytown) on the Atlantic and Brito on the Pacific are the termini of the canal, the total distance from port to port being 169.448 miles, of which 26.783 miles will be excavated canal and 142.659 miles free navigation by Lake Nicaragua, the river San Juan, and through basins in the valleys of the streams Deseado, San Francisco, and Tola. Lake Nicaragua is necessarily the summit level of the canal, and its elevation above mean sea level is taken at its mean as 110 feet. It will be connected with the Pacific by two sections of canal in excavation and the Tola Basin, and with the Atlantic by slackwater navigation through the valley of the river San Juan, and a series of basins in the valleys of the San Francisco and Deseado, connected by short sections of canal, the sea level on each side being reached by three locks, which have been located as near as possible to the extremities of the canal, viz, 3¼ miles from Brito and 12¾ miles from Greytown, thereby giving a clean summit level of 153½ miles in extent out of a total distance of 169½ miles, as stated above. For the purposes of this report the whole route has been divided into four divisions, viz, Eastern, San Francisco, Lake and River, and Western.

EASTERN DIVISION.

FROM THE INNER HARBOR OF SAN JUAN DEL NORTE (GREYTOWN) TO THE SAN FRANCISCO BASIN, 18.864 MILES.

The line selected and located starts from the inner harbor of San Juan del Norte and extends in a southwesterly direction for a distance of 9.297 miles to Lock No. 1, in the valley of the small stream Deseado, which descends from the high ridge separating the valley of the San Juanillo from that of the Caño San Francisco. Where the stream Deseado interferes with the course of the canal it is to be diverted by artificial channels. These first 9.297 miles of canal will be at the level of the sea, forming practically a prolongation of the harbor of Greytown, the width proposed allowing ample room for the passage of vessels going in both directions. The excavation will be entirely through flat alluvial deposits, as shown by the numerous borings taken along the whole line.

The first lock from this reach will have a lift of 30 feet and the uniform dimensions of chamber adopted for all the locks, viz, 650 feet long and 70 feet wide. A suitable bit of high ground for the site of the lock is met with in the lower valley of the Deseado. From the head gate of Lock No. 1 to Lock No. 2 the canal follows the valley of the Deseado, which is here partially flooded by the construction of four low embankments, connecting the site of Lock No. 1 with the sides of the valley. In this manner the canal excavation, which here consists chiefly of a stiff red clay underlying a thin strata of loam, is much reduced, and the drainage economically and efficiently controlled by suitable weirs of maximum flood capacity.

Lock No. 2, located 1.258 miles above the head gate of Lock No. 1, has a lift of 31 feet, and will rest on solid ground, a hill on the south side of the valley affording an excellent site for it.

Lock No. 3, with a lift of 45 feet, is located 12¾ miles from Greytown and 1.927 miles from the head gate of Lock No. 2. This section of the canal occupies the lower basin, made in the valley of the Deseado by the erection of a dam 38 feet high and 1,300 feet long across the stream, and two embankments of an aggregate length of 1,400 feet and about 20 feet high on the top of the confining ridges. The only excavation needed through this basin is in cutting across three low hills of red clay.

At this point the valley of the Deseado is spanned by an embankment 70 feet high and 1,050 feet long, resting on two high hills, and the gaps on the ridge connecting this embankment with the sides of the valley are closed with smaller embankments, aggregating 5,800 feet on the crest, with an average height of 20 feet to the level, 112 feet above sea level. By this means a basin 3.086 miles long is created in the valley of the stream, in which a depth of from 30 feet to 70 feet is obtained without excavation for a distance of 2.598 miles. It is proposed to retain the water in this basin at an elevation of 106 feet above sea level; in other words, the summit level of the canal is carried across the "Divide" and extended to Lock No. 3, or to within 12¾ miles of the Atlantic, and but 3¼ miles from the sea level, which, as stated above, reaches 9½ miles up from Greytown. The advantage of these two large reservoirs in close proximity to the locks used need not be commented upon, and the facilities afforded as a "turn out" for ships in waiting and traveling in opposite directions can not be overestimated. The dam is proposed to be built of stone, or what is termed "rock fill," with earth backing, and will have a weir 600 feet long on the crest and a fall of 45 feet for the discharge of the surplus water into the lower basin. This will be supplemented by another weir 800 feet long located on the south side of the valley in a gap between the hills inclosing the upper basin, giving a total length of weir of 1,400 feet.

At the western extremity of this basin begins the "Eastern Divide Cut," connecting the valley of the Deseado with that of the Caño San Francisco. This cut is 2.917 miles long, has a maximum cut of 298, and an average depth of 111.2 feet above the level of the water, the depth in the canal being 30 feet, and contains about 21 per cent of the total excavation estimated for the whole canal.

The magnitude of this work grows less striking as we proceed to examine its importance as a factor in the solution of the problem; the local advantages for its execution, its permanency when finished, and the advantageous and economical disposition of the material to be excavated.

First. It will be observed that this cut is almost in a direct line between Ochoa and Greytown, which are the two objective points of the canal; the former being the point at which it must of necessity leave the San Juan River, and the latter equally necessary as its terminus on the Atlantic.

Second. It is the lowest point along the whole ridge which intervenes between those two points, and nearly equidistant from each.

Third. It is also the narrowest pass, by several miles, of any other on the ridge, the valleys of the Deseado on one side and the San Francisco on the other, here penetrating it farther than elsewhere, thus allowing the greatest possible extension of their basins with the least excavation.

Besides the above, there are several other important advantages connected with this particular pass entitled to much consideration.

First. The material to be removed is in the main solid rock, therefore the volume of excavation is reduced to a minimum, and the cut when made will remain so forever without further expense.

Second. The material is needed for the construction of the dam at Ochoa, for the embankments between Ochoa and Greytown, for the construction of the locks, for the breakwater at Greytown, and for pitching the sides of the canal, and whatever is left over can be dumped in the immediate vicinity.

Third. The center of distribution is most conveniently located, and were not this material available, at the sole expense of transportation down grade, it would have to be obtained at considerable cost from quarries in the vicinity, as there is no rock easy of access between Ochoa and Greytown, except in this ridge.

Fourth. The locality is one of the healthiest in Nicaragua, the drainage is perfect, and water abundant and excellent for domestic uses.

Fifth. There is close at hand on both sides of the ridge an inexhaustible water power for the economical and convenient operation of all the machinery required to do the work.

Possessing, therefore, as it does, this truly marvelous coincidence of favorable circumstances, it would seem as though the very hand of nature had made this particular spot with the view of facilitating the execution of the greatest undertaking of this or any other age. With proper appliances and good management, so much of the work in the adjacent sections being dependent upon the material to be got from this cut, an even rate of progress can easily be maintained and the whole work be pushed to completion well within the six years estimated as the time for completing the canal.

SAN FRANCISCO DIVISION 12.500 MILES.

FROM THE WESTERN END OF THE DIVIDE CUT TO THE RIVER SAN JUAN AT OCHOA.

On the western slope of the divide the canal follows the valley of the Limpio for 1.477 miles to the end of the cut. Before falling into the San Francisco Basin it passes for 0.738 mile through a rolling country in the lower valley of the Limpio, the average depth of the cutting for this distance being 16 feet above the bottom of the canal.

Passing into the basin of the Caño San Francisco, it follows the valleys of the Limpio and Chanchos to near the confluence of the latter with the San Francisco, and then up the valley of the stream, skirting the hills on the west, to a favorable pass in the range separating this valley from the swampy region, called Florida Lake, extending toward Ochoa. The line of location follows this swamp to its western extremity, where it strikes the high rolling country intervening between this low region and the valley of the Machado, and following a tributary of the latter it strikes the river San Juan 1,600 feet above the mouth of the Machado. The distance from the western end of the Divide Cut to the bank of the river San Juan is 12.500 miles, of which 7.481 miles are tangents and 5.019 miles comprised in eleven curves of from 4,000 to 11,459 feet radius. The hills surrounding the basin on the south do not form an unbroken range rising at all points above the level of the water, which in this section also is maintained at 106 feet above sea level. Eight gaps will have to be closed by embankments aggregating in length to 2,440 feet measured on the valley floor, and 12,260 feet on the crest, the maximum depth being 60 feet below the level of the water in the basins.

In addition to the above, 59 smaller embankments, aggregating in length 18,280 feet on their crest, rising 6 feet above water level and varying in height from 1 to 50 feet, will be required from Ochoa to the main ridge of the divide. All the embankments resting on the valley or swamp level are designed of rock fill and earth backing, with three parallel rows of sheet piling between abutments.

The total length of basin secured by this plan is 11.267 miles from flowage line to flowage line, of which 8.697 miles is in water varying from 30 to 60 feet in depth; that is, of the 12.500 miles in the division but 1.233 miles will be wholly and 2.570 miles partly in excavation. This is not, however, the only advantage gained by the creation of this basin. Without it the cut across the Divide would be of such proportions as to make the route commercially impracticable, and the basin of the Deseado an impossibility. Not less important are the additional considerations of free navigation through a wide and deep basin, instead of a restricted excavated channel. In the former, vessels can travel at full speed, lie at anchor, or pass each other at all points, while in the latter the position and speed of all ships must conform to rigid regulations.

Attention is also invited to another striking feature of this work, as compared with that close to the bank of the San Juan.

In a country subject to observed rainfalls of more than 6 inches in twenty-four hours, the problem of drainage involves dealing with forces of nature, whose enormous destructive powers are a constant menace to engineering works, however careful and skillful their design and execution. And it is of the utmost importance, therefore, to reduce these forces to a minimum before the construction of works to withstand them. The large territory embraced between the ridge confining the basin to the south and the "Lower Route" is, by the adoption of the "Upper Route," entirely eliminated from the problem of drainage, leaving only that portion of the watershed north of the ridge, from the Divide to the valley of the Machado, to be provided for. The area of this catchment basin is about 65 square miles.

It is proposed to build all embankments across the valleys in the disconnected portions of the ridge of "rock fills" and earth backing, the crest to be 107 feet above sea level, and with the top and outer slope so shaped and paved with large stones as to admit the free flow of water over the surface without danger of injury, all other embankments to be 112 feet above sea level. All these embankments will be, in fact, so many wasteweirs for the discharge of the surplus water at several points in the basin, with an aggregate length of 4,720 feet of spillway; and assuming that the embankments are perfectly tight, which will not be the case until several years after construction, and therefore that all the surplus water passes over the weirs, the maximum thickness on the crest will not exceed 15 inches.

An extraordinary freshet in the San Juan above the dam would probably cause some of the river water to flow toward the basin, but it will be observed that the weirs in the basin alone are capable of discharging 90,200 cubic feet per second before the water reaches the top of the higher embankments, and that, in such extreme cases, the basin would also be discharging through the Divide Cut, over the Deseado Dam and weirs, and, if need be, through the culverts of Lock No. 3. As an additional precaution, a guard gate is provided in the first cut east of the Machado, by which the waters of the river San Juan may be shut off from the basin. With these ample provisions the destruction of the smaller earth embankments by an overflow of the basin seems to be well guarded against.

LAKE AND RIVER DIVISION 121.04 MILES.

FROM OCHOA TO THE WESTERN COAST OF LAKE NICARAGUA.

This division extends from the western extremity of the San Francisco Division in the valley of the Machado to the entrance of the canal on the west shore of Lake Nicaragua. The total distance is 121.04 miles, divided as follows: Navigation by the river San Juan, 64.54 miles; lake navigation, 56.5 miles. The section of the river from Ochoa to the lake is to be made navigable by the construction of a dam at Ochoa, just below the Machado, maintaining the water at the summit level of 106 feet above sea level. It may here be explained that this elevation, hitherto treated as the summit level, is 4 feet below the lake, a fall of three-fourths of an inch to the mile being allowed for the slope necessary to discharge its waters, although for all the purposes of navigation that portion of the river is converted into an extension of the lake.

The dam is located between two steep hills, and its length of weir on the crest will be 1,250 feet, and abutments 650 feet. The average depth of the water in the river was at the time of the survey 8 feet, and the maximum depth, close to the southern abutment, 14 feet, the width between banks being 950 feet. With a mean flow in the river of 20,000 cubic feet per second the thickness of water on top of the weir will be about 3¼ feet.

The dam is proposed to be built of rock fill and earth backing, in all respects similar to all the other large embankments and weirs already described. Its average height above the river bottom is 61 feet, its thickness at the top 25 feet, and at the bottom 500 feet. The core of the rock portion will be made of smaller stones, gravel, and refuse from the rock cuts, with three rows of sheet piling from abutment to abutment, and substantial concrete core walls from the ends of the sheet piling carried well into the abutment hills and up along the slope beyond the maximum flood level. The upper portion and long flat apron will be composed of stones of the largest dimensions that can be properly handled and arranged, the interstices being filled from behind with small stones, gravel, and earth dumped from suitable trestles.

By this dam, slack-water navigation in the river San Juan will be obtained in the whole distance from the lake, in which, with the exception of the 28 miles above Toro Rapids, the navigable channel will be at no point less than 1,000 feet wide, with depths varying from 28 to 130 feet. Between the lake and Toro Rapids, rock blasting under water and dredging to an average depth of 4¼ feet will be required at several places, amounting in all to 24 miles, most of the rock blasting occurring at Toro. The average depth of water as raised by the dam over the shallow places where deepening has been estimated for is 23 feet, and the excavated channel is 125 feet at the bottom, the slopes varying with the character of the material.

A further important effect of the dam will be to raise the water of the river San Carlos to the level attained by the San Juan at their confluence above Ochoa, converting the valley of that stream into a spacious lake or port, and an integral part of the summit level and of the canal itself. Thousands of square miles of the territory of Costa Rica now inaccessible by land or water will thus become the richest portion of that Republic; and the sediment now being brought down by the rapid current of the river will then be deposited, for want of transporting power, at the mouths of the ravines and mountain torrents emptying into the basin. In fact, the area now scoured will be so much reduced that comparatively little material will be transported.

The confining ridge to the east of the valley of the San Carlos is a generally high range extending in a nearly straight line from the south abutment of the Ochoa Dam about south 15° west 7½ miles to the foot of the high mountains of the interior. The length of the ridge following its crooked crest line is about 10 miles. The hills forming the ridge do not form an unbroken range at all points higher than the level of the water, which is here also maintained at 106 feet above sea level. A number of short depressions will have to be closed by embankments, the tops of which will be at an elevation of 112 feet.

The total number of embankments necessary is 21. Of these, 8 will be very small, the ridge being now above the water line but below 112 feet. Only 2 will reach the floor of the valley, having a depth of 48 feet. The remaining 11 have an average depth of 19 feet. The aggregate length of embankments on crest is 5,540 feet; on floor of valley, 130 feet.

The embankments proposed will be entirely of clay, 15 feet wide on top, with slope of 3 to 2 on both sides.

It is proposed to build a large waste weir in the ridge about 2¾ miles from the Ochoa Dam. This weir, having its crest of 106 feet elevation, will discharge the flood waters of the San Carlos into the San Juan independently of and below the dam.

The valley of Cureño Creek runs directly from the site of the proposed weir to the San Juan 5½ miles below Ochoa; hence no channel for the discharged waters need be provided.

In the east side of Lake Nicaragua, dredging, in soft mud, will be needed for a distance of about 14 miles to reach the depth of 30 feet, the average depth of the cut being 9.8 feet, and the proposed channel 150 feet wide at the bottom, with side slopes of 3 to 1 to the present bottom of the lake.

From the end of this cut to within 1,400 feet of the west coast, at the entrance of the canal, the depth in the lake varies from 30 to 150 feet. The excavation on the west side is estimated as rock. No borings were taken on this side of the lake, but the indications on the shore and the result of the borings in the vicinity, point to rock as predominating in the submarine excavation.

In view of the nature of the bottom and the prevailing winds on that coast of the lake, it has been deemed advisable, if not essential, to estimate for two crib piers or breakwaters at the entrance of the canal and extending to deep water, a distance of 1,800 feet and 2,400 feet, respectively. These piers will have the effect of arresting débris traveling along the coast by the action of the waves, insure smooth water at the entrance of the canal, and serve as guides to approaching vessels.

WESTERN DIVISION.

FROM THE LAKE TO BRITO 17.04 MILES.

This section of canal connects the lake with the Pacific Ocean. It is 17.04 miles long from the shore of the lake when at 102.5 feet above sea level, the elevation at the time the surveys were made, to the port at Brito.

As the canal is now estimated for, 11.44 miles of that distance will be wholly in excavation and 5.60 miles through a basin in the valleys of the rivers Grande and Tola.

In this basin from 30 to 70 feet of water can be had for a distance of 4.568 miles. The basin has an area of 4,000 acres, an extreme width of 12,500 feet, and an average of 5,500 feet. An alternative route has been located through the valleys proposed to be flooded, for a canal in excavation, should it be found more economical on account of the value of the land through which it passes. The only new feature of this division is the basin now introduced.

The first section begins at the mouth of the river Lajas, on the west shore of Lake Nicaragua, and follows the valley of that stream for a distance of 8,260 feet, in which the width of the canal is 120 feet at the bottom and the side slopes 1¼ to 1, both in rock and earth. The river Lajas here turns to the south, and it is proposed to divert it and make it discharge into the lake a short distance south of its present mouth. The canal continues on the same straight line, crosses a plain about three-quarters of a mile wide, and enters the valley of the Guiscoyal, a small tributary of the Lajas, and at 4.7 miles from the lake it crosses the highest elevation on the line between the lake and the Pacific. This point is 42 feet above high lake, or 152 feet above mean tide in the Pacific, and is situated in a valley about 2 miles wide, deserving special mention by reason of the fact that it is the lowest depression of the main ridge between the Atlantic and Pacific oceans on the American continent.

After crossing this divide, the line gradually descends at the rate of about 9 feet per mile, and in 1¾ miles farther it meets the Rio Grande, a mountain stream which drains an extensive area of the western slope of the Cordillera. The line of the canal follows the tortuous channel of the Grande, cutting across some of its sharp bends, or occupying the channel in short reaches. In 1¼ miles in frees itself from this contracted valley and cuts across a broad plain as it turns to the westward and enters the basin of Tola, 9 miles from the lake. The distance across the basin by the sailing line is 5.504 miles. This basin is formed by the construction of an embankment 1,800 feet long and 70 feet high, resting on two high hills at a place called La Flor. The method of construction of this embankment is in all respects similar to that adopted for the construction of the Ochoa Dam, and embankments in the San Francisco Valley. The rock for the fill will be obtained from the excavations for Locks Nos. 4 and 5, in the north abutment, and the earth from the canal excavation east of the basin.

The level of the lake will be extended through the divide cut and the basin to this dam, the top of which is established at 112 feet above sea level. Therefore, the lake will have to rise more than 2 feet above the proposed summit level before any water runs over the weir. With a length of weir of 1,300 feet and the lock culverts capable of discharging not less than 4,500 cubic feet per second, the level of the lake can be kept under control, even in extraordinary floods. Yet a guard gate is proposed in the section of canal between the lake and the "Divide" to shut off the water from the lake in case of necessity. No special provision has been made for the control of the rivers Grande and Tola, and none is deemed necessary. These streams will flow into the summit level, one between the lake and the Tola Basin, and the other at the northern extremity of the basin. The waters will be distributed between the basin and the lake, or partly used for feeding the locks, and should both rivers be in flood while the water in the basin is below the crest of the weir, and therefore most of the combined flow discharging into the lake, the current in the canal through its narrowest portion in the "Divide" will not exceed 2 miles an hour, which can do no harm in the rock cut, while in the larger portions of the canal the velocity would of course be proportionally less.

From the western end of the valley of Tola to Brito, the canal, after leaving Locks Nos. 4 and 5, cuts across a broad flat country, with an inclination of about 9 feet per mile, to the port, a distance of 2.28 miles, in which the excavation does not exceed that required for the canal prism.

These locks are proposed to overcome the difference of level between the summit and the Pacific. Locks Nos. 4 and 5 are located in the hill north of La Flor Dam;

their chambers are 650 feet long and 70 feet wide, and the lifts 42½ feet in each. Lock No. 6, of the same dimensions of chamber, is situated 1.58 miles below, its lifts being 21 feet and 29 feet, respectively, at high and low tides. Between this lock and the port of Brito, a distance of 0.57 miles, the canal will be at the level of the sea, with an enlarged section, and may be regarded as an extension of the harbor similar to that at the Greytown end of the route.

HARBORS.

GREYTOWN.

The observations and surveys conducted by the hydrographic party and subsequent investigations by other engineers of the company have fully confirmed the theory based on previous surveys as to the nature and magnitude of the forces which caused the destruction of this harbor, and consequently the plan heretofore recommended for resisting these forces and restoring the harbor is now adhered to with but slight modifications in the details.

The plan of restoration involves the construction of a jetty or breakwater 1,700 feet long, nearly normal to the shore of the outer bar, and extending to the 6-fathom curve, and dredging from this latter depth off shore across the sand bank now closing the harbor and in the inner bay. The jetty is located to the windward of the excavated channel which it is intended to shelter from the sea and protect from the wash of the waves and the traveling sands of the coast.

The first section of the jetty extending from the shore to 15 feet of water is proposed to be built of creosoted timber, fascinage, and stone, and that portion in deep water to be of "pierre perdue" or rubble, the stone to be obtained from the "Divide Cut." The entrance channel is estimated to have a depth of 30 feet and a width of 500 feet at the bottom, and the inner basin is designed of sufficient dimensions to afford easy access to the canal and to accommodate a large number of vessels, its excavated area on the bottom being 206 acres, which, with the area of the enlarged section of the canal at sea level to Lock No. 1, gives a total area of 341 acres of water 28 feet deep exclusive of slopes of 3 to 1 and the remaining portions of the inner bay not deepened, yet having in many places a depth of 20 feet, in which a large number of vessels of ordinary size can lie.

BRITO.

The recent surveys have greatly added to previous information as to the natural conditions of this locality, which, by reason of its being of necessity the terminus of the canal on the Pacific coast, has been spoken of as "the harbor," when, as remarked by Professor Mitchell, it is not even a roadstead. Yet the practicability of constructing a harbor at this point has not been disputed, the only difference of opinion being confined to details. The plan now proposed combines, as nearly as possible, the most economical form of construction with that best adapted to the physical conditions, and meets, it is believed, most effectually the objections raised against former designs.

The broad valley of the Rio Grande stretches to the coast at this point through a wide gap in the main range of hills extending along the Pacific coast. This valley, it is believed, formed once a considerable bay, but is now filled up for a distance of about 6,000 feet from the beach to about the level of high water. The proposed plan for the construction of the harbor consists, first, in a breakwater, 900 feet long, extending from a rocky promontory projecting from the beach at the western extremity of the range of hills, and, second, another jetty, 830 feet long, normal to the beach, nearly opposite the extremity of the one before mentioned. The proposed harbor will be partly in deep water confined by the jetties, but its main portion is proposed to be excavated in the alluvial valley, the whole forming a deep and broad basin penetrating 3,000 feet from the present shore line at high water and 3,900 feet from the entrance between jetties. As an extension of the harbor, the canal itself is excavated at sea level with an enlarged prism for a distance of 3,000 feet farther inland, where the tide lock has been located. It is believed that, with the basin as designed and the prolongation of the sea level through the canal, sufficient tranquillity will be secured at the lock and in the harbor; but should this prove not to be the case, an enlargement of the main basin by dredging in soft material would be a question of but comparatively small expense.

The breakwaters, as estimated for, are of "pierre perdue," the material to be obtained from the rocky promontory or from the western divide cut, the price allowed being on the latter basis. The harbor has an area of 95¼ acres on the bottom, or excavated portion, and with the sea-level section of the canal the total area is 103¾ acres of water, 30 feet deep, exclusive of the slopes of 3 to 1.

MATERIALS FOR CONSTRUCTION.

As has been stated in previous reports, the whole line of the canal is well supplied with timber, generally of excellent quality, though in some sections of the eastern division it has been deemed advisable to estimate for its use only on temporary works during construction, such as trestles, laborers' dwellings, etc., the sheet piling and most of the bearing piles being imported from the Southern States, and creosoted where necessary. On the western division however, the wood, growing on ground less moist, is of a very superior quality, and it is proposed to use it for all purposes, its durability having been amply proved in every class of construction throughout the country.

The rock proposed to be used for the dams, weirs, and breakwaters will be got from the divide cuts, which consist chiefly of basalt and various descriptions of trap of excellent quality for the purpose.

Lime of the best quality is obtainable in the western division at many places, and the numerous specimens of work on which it has been used have stood the test of many generations, and are to-day in a state of perfect preservation; but it is calculated to supplement this supply with imported cement, which will be used largely in the form of concrete in the construction of locks, etc., clean, sharp sand being found in great abundance in the beds of most of the streams in the vicinity of the canal.

DIMENSIONS AND CAPACITY OF THE CANAL.

In establishing the dimensions of the canal it has been my purpose to profit by the experience of the Suez Canal, where a yearly traffic of 6,000,000 tons could not be carried through without serious delays to navigation. The reduction in the length of excavated canal accomplished by the last location in Nicaragua through the substitution of free navigation in deep and broad basins for a restricted channel gives additional facilities for the construction of a waterway capable of accommodating not less than 12,000 vessels, with a net tonnage of 20,000,000 a year, at but a small increase cost as compared with the advantages secured, both for the commerce of the world and the economical administration of the enterprise. In fact, the immediate and prospective benefits obtained by the enlargement in the increased facilities for passing vessels and a considerable decrease in the cost of maintenance and preservation of the work fully justify, it is believed, the additional expense in the original cost. It will be seen, on examination of the subjoined table, that of the 169.448 miles, the total length of the canal from the Atlantic to the Pacific, 121.04 miles is unimpeded navigation in the river San Juan and in Lake Nicaragua, and 21.619 miles through basins, making a total distance of 142.659 miles in which ships can travel with little or no restriction as to speed. Of the remaining 26.789 miles, 0.759 is taken up by the six locks, leaving but 26.030 miles of canal actually in excavation. Of this latter distance 18.189 miles are of canal large enough for vessels traveling in opposite directions to pass each other, the sectional area being in excess of the largest area of the Suez Canal. The two sections of canal with contracted prisms are in the eastern and western divide cuts. The first is 2.917 miles and the other 4.924 miles in length, and located as they are, almost at the extreme ends of the summit level and in close proximity to the upper locks, it is believed that the slight additional facilities to navigation secured by enlarging the dimensions of the canal in these heavy rock cuts and the inconsiderable gain in the time of transit would not compensate for the larger outlay necessary.

Table showing the dimensions of the several sections of the proposed canal.

Section of canal.	Length.	Width of top.	Width of bottom.	Depth.	Area of prism.
	Miles.	*Feet.*	*Feet.*	*Feet.*	*Sq. feet.*
Greytown to Lock No. 1	9.297	288	120	28	5,712
Lock No. 1 to Lock No. 2, canal	1.258	210	120	30	4,950
Lock No. 2 to Lock No. 3, canal	.165	210	120	30	4,950
Lock No. 2 to Lock No. 3, basin	1.762	....	....	*a* 30	....
Lock No. 3 to western end of eastern divide cut, canal	2.917	80	80	30	2,400
Lock No. 3 to western end of eastern divide cut, Deseado Basin	3.086	....	....	*a* 45	(*b*)
Western end of divide cut to Ochoa, canal	1.233	184	80	30	3,673
Western end of divide cut to Ochoa, San Francisco Basin	11.267	....	....	40	(*b*)
River San Juan to Toro Rapids	37.040	....	....	*a* 52	(*b*)
River San Juan where dredging is needed	27.500	....	125	*a* 28	(*b*)
Lake Nicaragua	56.500	....	150	*a* 50	(*b*)
Lake to western divide cut, canal	1.565	210	120	30	4,950
Western divide cut, canal	4.924	80	80	30	2,400
Divide cut to east end of Tola Basin, canal	2.519	184	80	30	3,673
East end of Tola Basin to Lock No. 4, basin	5.504	....	....	*a* 50	(*b*)
Lock No. 5 to Lock No. 6, canal	1.582	184	80	30	3,673
Lock No. 6 to harbor of Brito, canal	.570	288	120	28	5,712

a Mean. *b* Undetermined.

Table showing the dimensions of the several sections of the proposed canal—Continued.

RECAPITULATION.

Section of canal.	Miles.	Length.	Remarks.
		Miles.	
Canal in excavation, east side	14.870	....	
Canal in excavation, west side	11.160	....	
Six locks, both sides	.759	26.789	Total canal in excavation.
Basins of the Deseado	4.848	....	
Basin of the San Francisco	11.267	....	
Basin of the Tola	5.504	21.619	Total length of basins.
River San Juan	64.540	....	
Lake Nicaragua	56.500	121.040	Total natural waterways.
From the Atlantic to the Pacific	....	169.448	Total length of canal.

In the lake and in the greater part of the river San Juan vessels can travel with unrestricted speed, and in some sections of the river and in the basins, although the channel is at almost all points deep and of considerable width, the speed will be somewhat checked by reason of the curves.

Official reports show that in the Suez Canal steamers of 4,400 tons can travel at an average speed of 6 statute miles per hour, and that smaller vessels travel through the canal at the rate of from 6 to 8 miles an hour. On this basis the following estimate of the time of transit has been prepared:

Estimated time of through transit by steamer.

	h.	m.
26.030 miles of canal, at 5 miles an hour	5	12
21.619 miles in three basins, at 7 miles an hour	3	05
64.540 miles in the river San Juan, at 8 miles an hour	8	04
56.500 miles in Lake Nicaragua, at 10 miles an hour	5	39
Six lockages, at 45 minutes each	4	30
Allow for detentions, in narrow cuts	1	30
Total time of transit	28	00

The traffic of the canal will be limited by the time required for a vessel to pass a lock, and on the basis of forty-five minutes, and that but one vessel will pass in each lockage, the number of vessels that can pass through the canal in one day will be 32, or in one year 11,680, which, at the average tonnage of vessels going through the Suez Canal, will give an annual traffic of 20,440,000 tons. This estimate is on the assumption that the traffic will not be stopped during the night, for with abundant water power at the locks and at the basins the whole canal can be economically illuminated by electricity, and with beacons and range lights in the lake and river there seems to be no good reason why vessels should not travel day and night with perfect safety, and the outlay necessary for the illumination has consequently been included in the estimates.

WATER SUPPLY.

Lake Nicaragua has a surface area of about 2,600 square miles, and a watershed of not less than 8,000 square miles. Gauges of its outlet, the river San Juan, at its lowest stage between the lake and Toro Rapids showed a minimum flow of 11,390 cubic feet per second. Colonel Childs estimated the discharge with full lake in the wet season at 18,059 cubic feet per second, which gives a mean flow of 14,724 cubic feet per second, or 1,272,530,600 cubic feet per day.

Water required for lockage.

Water required for—	Cubic feet
One lockage on the east side	2,047,500
One lockage on the west side	1,933,750
One lockage on both sides	3,981,250
Thirty-two lockages per day	127,400,000

This gives a daily excess for the lake supply only of 1.144,753,600 cubic feet.

To the latter amount must be added the flow of the several tributaries of the San Juan River between the lake and the Ochoa Dam, and also the tributaties of the basins forming part of the summit level, which would fully compensate for leakage and evaporation.

It is expected that considerable leakage will take place at the rock-fill dams and embankments before they consolidate and become tight, but this may well be accepted as a desirable condition to aid in gradually disposing of the surplus water without a large discharge over the weirs.

The above statement shows that the lake discharge is about ten times larger than the maximum amount needed for the canal, and it may be safely estimated that for many years after the canal is opened for traffic the surplus from that source alone will be double that amount, while at the confluence of the rivers San Juan and San Carlos, above the Ochoa Dam, the excess may even reach forty times the quantity needed for the canal. It is evident, therefore, that as long as the summit level can be maintained at the required elevation, the leakage through the rock fills, acting as safety valves, may be regarded as an element of security rather than one of danger, especially as the tightening of the dam can be regulated by depositing suitable material on the upstream side or by dumping more stone on the lower slopes or on the crest, so as to preserve the desired elevation of the surface of the water.

ESTIMATES.

The estimate of the cost of the canal submitted with this report is the result of careful computations of all the works required for the completion of the canal and its accessories, based upon the data obtained by the last location, with numerous borings along the whole route. Where no rock was met with the borings were carried to the bottom of the canal, and all material which the auger or hand drills could not penetrate has been assumed to be, and estimated for, as rock. The result is a much larger amount of rock in proportion to the cube to be removed than had been estimated before; and although the length of canal in excavation has been reduced by 13.5 miles and the total amount of excavation by 3,567,565 cubic yards, in that portion covered by the report of 1885, yet the cost of that item of expense is now put down at $31,936,136.05 as compared with $33,447,338.80 in 1885. It is believed that when a more effective system of drilling is applied in certain portions of the line a much smaller amount of actual work will be found than now appears on the estimate. In the meantime, the error, if any, is made on the safe side. The eastern "Divide Cut," of but less than 3 miles in length, is represented in the estimate with 7,000,230 cubic yards of rock in place and 22 per cent of the cost of the whole work, and reference has been made, in describing the eastern division, to the existing facilities for doing this work and to the several purposes to which the material to be removed can be advantageously applied in the construction of the canal for the expense of transportation alone.

In the western division the excavation in rock through the divide cut is estimated at 5,696,507 cubic yards in a distance of 9 miles, but that work presents no serious difficulties, the maximum depth of excavation being only 42 feet above the surface of the water in the canal, and the mean only 20 feet, with ample facilities for disposing of waste material not needed for construction of the breakwaters, the locks, the embankments, and pitching the slopes of the canal.

A comparison of the figures given in the estimate with those of the 1885 report discloses what at first sight appears to be an inconsistency, viz, an increase in the total estimated cost of the canal of $1,047,978.25, and a decrease in the length of actual canal to be excavated of 13.5 miles, and in the cube to be removed of 3,567,565 cubic yards, as stated before. It will, however, be observed that the surveys made by the expedition of 1885 were confined exclusively to the land portions of the canal, the estimates for the other portions being based on previous incomplete hydrographic surveys, while the recent location, covering, as it does, the whole line from ocean to ocean, has produced the following results:

First. A reduction of the quantities in all the sections actually located by the 1885 expedition by the introduction of basins, etc., and certain modifications in detail in the location, thus: 54,015,602 cubic yards excavation in canal proper in 1885 report, and 50,448,037 cubic yards by present estimate, a difference of 3,567,565 cubic yards in favor of the new location; though with regard to cost this has been more than balanced by the increase in the proportion of rock now estimated, as already explained.

Second. In all the work connected with the lake and harbor of Greytown the increase in consequence of the more accurate data now obtained is for excavation in the lake of 4,902,908 cubic yards against 877,675 cubic yards in 1885, and in the harbor of Greytown of 9,550,000 cubic yards against 4,080,100 cubic yards. Besides, the addition of certain other improvements, which have been spoken of in the copy of this report, fully explaining the apparent contradiction between the claims and the results of the recent expedition and giving further evidence of its extensive scope as well as its minute attention to detail, making it, as claimed, an improved location, the estimated cost only increased by more accurate knowledge of the country and conditions.

Of the 26.789 miles of canal in excavation, more than 12 miles will be done by dredging, the material to be deposited directly on both sides of the cut, and the short cuts in the San Francisco division, amounting in the aggregate to 1½ miles, are subdivided in small sections across narrow ridges separating deep valleys, where the excavated material not needed for embankments can be dumped in the immediate vicinity.

A railroad has been estimated for from Lock No. 1 to the dam at Ochoa, and between Lake Nicaragua and the Pacific, which, together with the lake and river and the smaller streams penetrating into the valleys of the Deseado and San Francisco, will afford easy and economical communication along the whole route. These small streams will be of special value at the start, as they proved to be in the prosecution of the surveys. It is admitted that the prices adopted in estimating the cost of this work should be greater than would be required for similar work located in any well-developed section of this country. A large percentage of the increased cost is chargeable to the transportation of tools and machinery and to the difficulty in obtaining and providing for the workmen, the country from Greytown to the lake being uninhabited, and that between the lake and Brito but sparsely populated. The erection of houses for the protection of the property and accommodation of employees will be a necessary item of expense; but the country is exceptionally healthy, and these structures need not be either substantial in character or expensive. The majority need be but temporary sheds built with material gathered along the line of the canal, at but little more cost than the labor in handling it; yet, some delay and expense may be found unavoidable in the preliminary preparations for commencing the work.

Another contingency which may cause a marked increase in the cost of the work is the physical inability of the imported workmen to perform the ordinary labor, as compared with that accomplished in a more temperate climate. The laboring classes of Nicaragua when under proper control are capable of an activity and endurance under great fatigue and exposure to the elements scarcely equaled in any other country, and with no apparent injury to health; yet the same capabilities can not be expected in unacclimated foreigners, accustomed to different conditions of life. It is believed that not less than 6,000 excellent laborers can be obtained from the Central American States, and that with a judicious management all the help needed can be had from the Gulf States in this country where the climatic conditions are in many respects similar to those prevailing over a large portion of the canal route. The number of skilled laborers employed will be comparatively small. On the west side of the lake, where the greater number of laborers will be employed, the climate is not excelled for salubrity by any other portion of Central America, and in that portion of the eastern section from Ochoa to Greytown, which is the only locality where trouble from climatic causes might be expected, the unexceptional good health enjoyed by the employees of the company during more than six months of constant exposure to the influence of the climate, while undergoing all kinds of hardships and privations, seems to be an evident demonstration that no apprehensions need be entertained as to the climate. It will be observed that in this section the work is divided into two large classes, viz, the divide cut and dredging. The first is located in the most elevated and healthy portion of the line, and in the second the number of employees is reduced to a minimum, as manual labor is almost entirely excluded. The small force necessary to handle and care for the machinery will be either housed on the dredges or in quarters in the "Divide" where, with the purest of waters from the mountain streams and the cool "Trades" constantly sweeping in from the sea, the slightest sanitary regulations will insure perfect health at all times.

The prices adopted are believed to be ample to cover all possible contingencies, provided the work is conducted by an intelligent and business-like management.

It is estimated that the canal can be completed in six years, of which time one year will be expended in marking out the line and clearing the ground and in making the necessary preparations to commence active operations.

CONCLUSION.

In closing this report I beg to express my firm convictions, the result of several years of constant labor and careful investigations, that the route here described and recommended is perfectly practicable, free from complicated engineering problems, and the most economical as well as the safest for interoceanic ship communication between the Atlantic and Pacific oceans, across the American isthmus.

In making this location, the information obtained by previous surveys and explorations has been utilized with much saving of time and labor, and has greatly contributed to the thorough knowledge of the country traversed by the canal now in possession of the company; and it may be safely stated that the present location can not be materially improved upon.

I take pleasure in expressing my high appreciation of the valuable services rendered by the officers of the expedition, to whose untiring energy and devotion to duty, under many adverse conditions, is due the success of the surveys. With such a large and efficient staff, in which the prevailing sentiment of each seems to have been to excel in the discharge of his duties, it is not in my power to make individual references to merit, but my sincere thanks are extended to all; yet I feel confident I can make two exceptions with the unanimous approval of all concerned.

Subchief R. E. Peary, on whom devolved the onerous duty of taking the surveying expedition to Nicaragua, displayed from the moment of his arrival in the country the most untiring energy, perseverance, and ability in the proper management and distribution of the force under his charge and in pushing the work forward, deserving the highest commendation. After I took charge of the work his cooperation was equally valuable.

The other is Mr. J. Francis Le Baron, who has been for the last six months in charge of the surveying parties left in Nicaragua, and has rendered very valuable services in completing and perfecting the location of certain portions of the route where additional information was deemed necessary.

The medical corps rendered most important services, both in attending to the sick and in giving preventive advice, which proved both valuable and effective. It shared also in the field work and in the drafting at headquarters.

Respectfully submitted.

A. G. MENOCAL, *Chief Engineer.*

NICARAGUA CANAL.—ESTIMATES OF COST ON LOCATION OF 1887-1890.

EASTERN DIVISION, 18.864 MILES.

[From Greytown to the eastern limit of the San Francisco Basin.]

Section 1.—From Greytown to the Divide, 15.947 miles.

1,819,820 cubic yards excavation in earth above water, at 40 cents	$727,928.00
13,547,597 cubic yards dredging, at 20 cents	2,709,519.40
172,288 cubic yards stone pitching sides of canal, at $2	344,576.00
925 acres grubbing and clearing, at $100	92,500.00
Lighting canal (at one-half mile intervals) 24 incandescent electric beacons and plant	67,000.00
Lighting locks, 30 electric arc lights with separate dynamos for each lock	9,000.00
Total	3,950,523.40

Section 2.—The Divide, 2.917 miles.

7,000,230 cubic yards excavation in rock, at $1.50	$10,500,345.00
3,034,904 cubic yards excavation in earth, at 40 cents	1,213,961.60
169 acres grubbing and clearing, at $100	16,900.00
Lighting canal (at one-half mile intervals), six incandescent electric beacons and plant	8,500.00
11,600 linear feet of narrow section of canal to receive double fender wales each side, at $4	46,400.00
Total	11,786,106.60

Railroads and telegraphs.

12 miles railroad from Lock No. 1 to San Francisco Basin, at $60,000	$720,000.00
22 miles telegraphs, Greytown to San Francisco Basin, at $500	11,000.00
Total	731,000.00

Lock No. 1.

463,603 cubic yards excavation in earth, at 40 cents	$185,441.20
120,044 cubic yards concrete (rock obtained from the Divide Cut), at $6.	720,264.00
2,400 cubic yards stone pitching in basin, at $2	4,800.00
3,699 cubic feet fender wales, at 50 cents	1,849.50
1,020 fender piles 45 feet long, at $13.50	13,770.00
Gates	114,934.40
Machinery	100,000.00
Buildings	30,000.00
Pumping	100,000.00
Total	1,271,059.10

Lock No. 2.

308,918 cubic yards excavation in earth, at 40 cents	$123,567.20
120,430 cubic yards concrete (rock obtained from the Divide Cut), at $6	722,580.00
2,400 cubic yards stone pitching in basin, at $2	4,800.00
3,699 cubic feet of fender wales, at 50 cents	1,849.50
1,020 fender piles 45 feet long, at $13.50	13,770.00
Gates	114,934.40
Machinery	100,000.00
Buildings	30,000.00
Total	1,111,501.10

Lock No. 3.

528,673 cubic yards excavation in earth, at 40 cents	$211,469.20
147,627 cubic yards concrete (rock obtained from the excavation), at $6	885,762.00
32 fender cribs, at $500	16,000.00
Gates	188,440.00
Machinery	100,000.00
Buildings	30,000.00
Total	1,631,671.20

Harbor of Greytown.

Brush-and-pile pier, 900 feet long	$190,214.50
225,907 cubic yards stone in breakwater (from Divide Cut), at $1.50	338,860.50
9,550,000 cubic yards dredging sand, at 20 cents	910,000.00
Piers at entrance to canal	100,000.00

Lighting and buoying.

One first-order light-house complete	$100,000.00
Three range beacon lights	1,000.00
One breakwater beacon light and signal tower	7,000.00
Two pier-head lights	2,000.00
One first-class (middle channel) Nun buoy	200.00
Two second-class (side channel) Nun buoys	200.00
Two third-class (side channel) Nun buoys	100.00
Total	2,649,575.00

Auxiliary works.

105,500 cubic yards dredging in earth and sand in diversion of Deseado, at 20 cents	$21,100.00
Embankment and weirs in valley of the Deseado:	
210,625 cubic yards rock fill (from the Divide Cut), at 40 cents	84,250.00
836,329 cubic yards earth in embankments and backing of weirs, at 30 cents	250,898.70
79,658 cubic yards excavation of surface soil for embankments, at 40 cents	31,863.20
5,100 linear feet of sheet piling 30 feet long, 8 inches thick, say, 1,350,000 feet, B. M., at $70	94,500.00
250,000 feet, B. M., timber for cross-ties and guides for sheet piling, etc., at $60	15,000.00
200 bearing piles for trestles and guides to sheet piling, at $10	2,000.00
2,500 linear feet of trestles for dumping stone, etc., at $22	55,000.00
Total	554,611.90

RECAPITULATION, EASTERN DIVISION.

Section 1, from Greytown to the Divide	$3,950,523.40
Section 2, the Divide	11,786,106.60
Railroad and telegraphs	731,000.00
Lock No. 1	1,271,059.10
Lock No. 2	1,111,501.10
Lock No. 3	1,631,671.20
Harbor of Greytown	2,649,575.00
Auxiliary works	554,611.90
Total	23,686,048.30

SAN FRANCISCO DIVISION, 12.5 MILES.

[From the western end of the eastern "Divide Cut" to the River San Juan.]

725 acres, clearing trees from line of canal, at $100	$72,500.00
30,309 cubic yards excavation in rock, at $1.50	45,463.50
2,698,195 cubic yards excavation in earth, at 40 cents	1,079,278.00
Lighting canal at one-half mile intervals, 24 incandescent electric beacons and plant	65,000.00
Guard gate or movable dam to control waters of the San Juan	300,000.00
Total	1,562,241.50

Railroad and telegraphs.

15 miles railroad, at $60,000	$900,000.00
40 miles of telegraphs from Divide to Castillo, at $500	20,000.00
Total	920,000.00

Embankments and weirs in the valley of the San Francisco.

3,239,705 cubic yards earth in embankments from canal excavation, at 30 cents	$971,911.50
1,575,459 cubic yards rock fill from the "Divide Cut," at 40 cents	630,183.60
192,415 cubic yards excavation of surface soil for embankments, at 50 cents	96,207.50
12,600 linear feet of sheet piling 40 feet long, 8 inches thick, say, 4,500,000 feet, B. M., at $70	315,000.00
1,458 guide piles for sheet piling and for bearing trestles, average 30 feet long, at $8	11,664.00
524,000 feet, B. M., of timber in guides and cross-ties for sheet piling, etc., at $60	31,440.00
27,585 linear feet of trestles for dumping rock and carrying railroad, at $22	606,870.00
178 acres grubbing and clearing for embankments, at $100	17,800.00
Total	2,681,076.60

RECAPITULATION, SAN FRANCISCO DIVISION.

Excavation, lighting, clearing, etc	$1,562,241.50
Railroad and telegraphs	920,000.00
Embankments and weirs in valley of the San Francisco	2,681,076.60
Total	5,163,318.10

LAKE AND RIVER DIVISION, 121 MILES.

[From Ochoa to the western shore of Lake Nicaragua at the mouth of the Rio Lajas.]

Section 1.—Rio San Juan, 64.5 miles.

398,613 cubic yards excavation in rock under water, at $5	$1,993,065.00
422,540 cubic yards excavation in earth above water, at 40 cents	169,416.00
2,150,900 cubic yards dredging in earth at, 30 cents	645,270.00
377 acres grubbing and clearing across bends, at $100	37,700.00

Lighting and buoying.

10 middle channel spar buoys (Fort San Carlos to Toro), at $25	$250.00
80 Western River light beacons, at $50	4,000.00
One electric arc lamp in signal tower at dam	3,000.00
Three incandescent electric-light beacons at dam basin	1,000.00
70 miles telegraphs, at $500	35,000.00
Total	2,888,701.00

Section 2.—Lake Nicaragua, 56.5 miles.

176,832 cubic yards submarine rock excavation (west shore of lake), at $5	$884,160.00
4,726,076 cubic yards dredging (east side of lake), at 20 cents	945,215.20

Lighting and buoying.

One fourth-order lens in signal tower at mouth of Rio Lajas	$7,000.00
One 2-mile range beacon	100.00
One fourth-order lens in keeper's dwelling at end of Solentiname Island.	6,000.00
One second-order lens on hill, old Fort San Carlos	8,000.00
One fourth-order range light in signal tower (old Fort San Carlos)	7,000.00
One second-class (middle channel) Nun buoy (at mouth of Lajas)	100.00
Two third-class (side channel) Nun buoys (at mouth of Lajas)	100.00
Five third-class (middle channel) Nun buoys (at entrance Rio San Juan)	150.00
Total	1,857,825.20

Dam across Rio San Juan at Ochoa.

18,500 cubic yards excavation in earth, at 40 cents	$7,400.00
1,550 cubic yards concrete in core walls of abutments, at $10	15,500.00
830 bearing piles for trestles and sheet piling 45 feet long, at $13.50	11,205.00
3,330 lineal feet of sheet piling 30 feet deep by 8 inches thick, 800,000 feet, B. M., at $75	60,000.00
1,180,000 feet, B. M., of timber in trestles, guides for sheet piling, cross-ties, etc., at $60	70,800.00
807,920 cubic yards rock fill (from Divide cut), at 50 cents	403,960.00
629,090 cubic yards earth filling from excavation, at 25 cents	157,272.50
Total	726,137.50

Embankments on San Carlos Ridge line.

293,240 cubic yards earth in embankments (borrowed), at 70 cents	$205,408.00
22,370 cubic yards excavation of surface soil, at 50 cents	11,185.00
450 lineal feet sheet piling 40 feet long 8 inches thick, 144,000 feet, B. M., at $70	1,510.00
45 guide piles for sheet piling, averaging 30 feet long, at $8	360.00
18,000 feet, B. M., of timber in guides and cross-ties, for sheet piling, etc., at $60	1,080.00
3½ acres grubbing and clearing for embankments, at $100	350.00
Total	219,893.00

RECAPITULATION, LAKE AND RIVER DIVISION.

Section 1, river San Juan	$2,888,701.00
Section 2, Lake Nicaragua	1,857,825.20
Embankments in San Carlos Ridge line	219,893.00
Dam across Rio San Juan at Ochoa	726,137.50
Total	5,692,556.70

WESTERN DIVISION, 17.04 MILES.

Section 1.—From Lake Nicaragua to Brito, 17.04 miles.

5,696,507 cubic yards excavation in rock above water, at $1.25	$7,120,633.75
5,399,316 cubic yards excavation in earth above water, at 40 cents	2,159,726.40
1,066,666 cubic yards dredging in sand, at 20 cents	213,333.20
20,753 cubic yards stone pitching sides of canal, at $2	41,506.00
1,033 acres grubbing and clearing, at $50	51,650.00
Lighting 20 incandescent electric beacons and plant	54,000.00
30 electric arc lights and 2 separate dynamos at locks	9,000.00
26,000 lineal feet of narrow section of canal to have double fender wales each side, at $4	104,000.00
Total	9,753,849.35

Diversion of the Rio Lajas into the lake.

249,508 cubic yards excavation in earth, at 40 cents	$99,803.20
164,786 cubic yards excavation in rock, at $1.25	205,982.50
Total	305,785.70

Railroad and telegraphs.

18 miles narrow-gauge railroad, at $25,000	$450,000.00
18 miles telegraphs, at $500	9,000.00
Total	459,000.00

La Flor Dam.

17 acres grubbing and clearing, at $50	$850.00
320,000 cubic yards excavation of surface soil, at 40 cents	128,000.00
3,320 lineal feet of sheet piling in two rows 30 feet long 8 inches thick, 796,800 feet, B. M., at $75	59,760.00
322 bearing piles for trestles and guiding sheet piling 20 feet long, at $5	1,610.00
50,000 feet, B. M., of lumber for guides and cross-ties for sheet piling, at $50	2,500.00
1,600 lineal feet of trestles for dumping material, at $22	35,200.00
918,000 cubic yards earth from canal excavation, at 20 cents	183,600.00
830,000 cubic yards rock fill from excavation for locks, at 20 cents	166,000.00
Total	577,520.00

Locks Nos. 4 and 5.

664,194 cubic yards excavation in rock, at $1.25	$830,242.50
127,646 cubic yards excavation in earth, at 40 cents	51,058.40
100,000 cubic yards concrete (rock from the excavations), at $6	600,000.00
1,020 fender piles, at $13.50	13,770.00
3,699 cubic feet fender wales, at 50 cents	1,849.50
2,400 cubic yards stone pitching in basin, at $2	4,800.00
Gates	250,000.00
Machinery	150,000.00
Buildings	45,000.00
Total	1,946,720.40

Tidal Lock No. 6.

61,698 cubic yards excavation in rock, at $1.25	$77,122.50
124,800 cubic yards excavation in earth, at 40 cents	49,920.00
126,000 cubic yards concrete (rock obtained from the Divide cut), at $6	756,000.00
1,020 fender piles, at $13.50	13,770.00
3,698 cubic feet of fender wales, at 50 cents	1,849.00
2,400 cubic yards stone pitching in basin, at $2	4,800.00
Gates	114,934.40
Machinery	100,000.00
Buildings	30,000.00
Pumping	100,000.00
Total	1,248,395.90

Other auxiliary work.

Guard gate or movable dam in the Divide	$300,000.00
Crib piers at lake entrance to canal	493,710.00
Three swinging bridges over canal	60,000.00
189,016 cubic yards embankment near site of locks, at 50 cents	94,508.00
19,080 cubic yards masonry walls at head of Lock No. 4, at $10	190,800.00
Total	1,139,018.00

Harbor of Brito.

5,658,898 cubic yards dredging, at 20 cents	$1,131,779.60
383,899 cubic yards stone in breakwaters (stone from Divide cut), at $1.50	575,848.50
Lighting and buoying one second-order lens in signal tower on promontory	10,000.00

One range-light beacon, inner base of promontory	$100.00
Two pier-head lights	2,000.00
One first-class (middle channel) Nun buoy	200.00
Four third-class (side channel) Nun buoys	200.00
Total	1,720,128.10
Right-of-way indemnity	100,000.00

RECAPITULATION, WESTERN DIVISION.

Section 1, canal	$9,753,849.35
Diversion of the Rio Lajas into the lake	305,785.70
Railroads and telegraphs	459,000.00
La Flor Dam	577,520.00
Locks Nos. 4 and 5	1,946,720.40
Tidal Lock No. 6	1,248,395.90
Other auxiliary works	1,139,018.00
Harbor of Brito	1,720,128.10
Right-of-way indemnity	100,000.00
Tipitapa Canal	275,000.00
Total	17,525,417.45

GRAND RECAPITULATION.

Eastern Division	$23,686,048.30
San Francisco Division	5,163,318.10
Lake and River Division	5,692,556.70
Western Division	17,525,417.45
	52,067,340.55
Surveys, hospitals, shops, management, and contingencies, 25 per cent.	13,016,835.45
Grand total	65,084,176.00

Respectfully submitted.

A. G. MENOCAL, *Chief Engineer.*

NOTE.—January 31, 1890. These estimates have been revised to conform to information obtained to date.

APPENDIX K.

THE WORLD'S COLUMBIAN WATER COMMERCE CONGRESS, CHICAGO, 1893.

THE NICARAGUA CANAL.

By A. G. MENOCAL, M. A. S. C. E., Etc.

It is assumed that the reader is sufficiently acquainted with the early history of isthmian transit and the various tentative explorations and surveys conducted under the auspices of the United States Government, and by private individuals, from Tehuantepec to the southern limits of the Isthmus of Darien, with the view of ascertaining the most practicable route for the safe and economical construction of the canal, and that, after several years of most careful and thorough investigation, regardless of expense and labor, the field of inquiry was narrowed down to Panama and Nicaragua.

In 1876 a high Commission appointed by the Government gave its final decision in favor of the latter route as possessing the greatest facilities for the economical and safe construction of a waterway between the Atlantic and the Pacific. This decision was later on disregarded by the Paris International Canal Congress, for in May, 1879, it voted in favor of a sea-level canal at Panama as the most advantageous and desirable route for a profitable enterprise and a safe waterway. The sad history of that unfortunate undertaking is ample justification of the action of the Commission and an unquestionable proof of the soundness of their conclusions. And yet it may be proper to say that the plans now under consideration are far more complete than those considered and indorsed by the Commission.

THE SURVEYS.

Government investigation and American enterprise did not rest with that decision. There was a restless desire to improve, if possible, on what was already known to be good; and, regardless of the attempt (which it was believed would prove fruitless) to overcome insurmountable difficulties at Panama, Government expeditions and private surveying parties succeeded each other at Nicaragua from 1880 to 1890, and the whole ground was gone over again. Every river, water course, valley, swamp, or hill likely to affect the construction of the work was carefully examined. Thousands of miles of transit and level lines were run in some sections of the route before a mile of canal location was finally decided upon; and this data, together with numerous borings, penetrating to the bottom of the canal, and at the sites of dams, locks, and embankments, comprise a vast store of exact knowledge, from which a final location has resulted, as perfect in its details, it is believed, as the natural conditions will permit. The greatest obstacles met with at other localities are high elevations in the Cordillera separating the two oceans, requiring tunneling, or a high summit level with a large number of locks for which an adequate water supply was not obtainable, or torrential streams are encountered whose control within economical limits defies the skill of the engineer.

Nicaragua is free from all these obstacles.

NICARAGUA LAKE AND RIVER.

The great lake, a veritable inland sea, 110 miles in length by an average of 40 in width, is the recipient of a watershed of 8,000 square miles, of which its water area represents nearly one-half. Its outlet, the river San Juan, is a noble stream. Its source is at the southeastern extremity of the lake, and flows through a broad valley, almost due east, for a distance of 119 miles, to its mouth in the Caribbean Sea, south of Greytown. Its minimum flow is 12,000 cubic feet per second; the width varies from 800 feet to 2,000 feet, and the average fall is 11 inches per mile. It main source of supply is the lake, which, by reason of its large area, restricted watershed, and ample outlet, is not subject to sudden or large fluctuation in level. Both the lake and river are therefore free from floods; and it is this important, invaluable feature which distinguishes this route from all others, and which enables us to make use of the lake and a large portion of the river as parts of the canal. The lake is separated from the Pacific by a narrow strip of land, a true isthmus, but 12 miles wide at its narrowest point. It is at this point, also, that is found the lowest depression in the Cordillera all the way from the Arctic region to Cape Horn, and the summit, or crest, of the ridge rises but 42 feet above the lake, or 152 feet above the sea. Through this gap will be cut that section of the canal connecting the lake with the Pacific, and terminating on the coast at Brito, a small roadstead where a harbor is to be constructed. From the lake eastward the river San Juan supplies the transit route to a point below its confluence with the San Carlos tributary, where the canal leaves the channel of the stream by a series of short sections in excavation, connecting a chain of artificial basins, and stretches in a well-maintained straight line to Greytown, the Atlantic terminus of the waterway. This general outline and an inspection of the map and profile will materially assist in arriving at a clear understanding of the route and engineering works proposed, which will now be described in detail.

THE CANAL ROUTE.

The lake, which is the controlling feature of the whole problem, is necessarily the summit level of the canal. The average yearly fluctuation of level due to wet and dry seasons is about 5 feet, its highest watermark being 110 feet above the sea; and that is the elevation assumed for the highest summit level of the canal. A direct sailing line between the outlet at Fort San Carlos, on the east coast, and the mouth of the River Lajas on the west, a distance of 56.5 miles, comprises the lake navigation proper. On that line the 30-foot contour (below the assumed level of 110 feet) is met with, about 14 miles from the outlet and 1,200 feet from the west shore. Between those points the depth gradually increases to 150 feet or more, the free navigable portions comprising the greater part of the lake area. Dredging in mud to an average depth of 9 feet will be required in the 14 miles on the east, and rock blasting and dredging in the 1,200 feet near the west shore. Two piers are proposed on the west coast to protect the canal entrance.

While the isthmus separating the lake from the Pacific is at its narrowest point not more than 12 miles in width, the most economical route connecting the lake shore with Brito has a length of 17.04 miles. It starts from the mouth of the Lajas, a small stream draining a limited watershed to the south of the line, and trends westerly through a broad valley slightly rising toward the "Divide," which it reaches at a distance of 4.7 miles from the lake. Descending thence on the Pacific slope, at the rate of about 9 feet per mile, at a farther distance of 1¾ miles it falls into the narrow, tortuous valley of the Grande, a dry creek during the dry season, but a stream of considerable flow in the rainy portion of the year. Its maximum volume has been estimated as high as 10,000 cubic feet per second; but this is attained only in times of extraordinay precipitation. In this narrow valley, confined by spurs of considerable elevation projecting from the highlands on both sides, there is not room for the canal and for an independent channel for the stream. A very favorable location has been made for the former, and it will be shown later on what disposition is proposed to be made of the stream. In 1½ miles the Grande makes a detour to the westward; and the canal, free from the confining hills on the north, cuts across a broad valley to fall again into the stream at a distance of 9 miles from the lake. At this point the surface of the ground is 30 feet below the assumed level of the lake. The valley continues its uniform descent of about 8 feet to the mile, and gradually expands until, at the junction of the Tola tributary, it attains the maximum width of 12,500 feet. At milepost 14, near a place called La Flor, the Grande passes through a narrow gap, flanked by high hills, into the more extensive plain of Brito, bordering on the Pacific. It was the original plan to cut a canal through this valley of Tola, and four locks were contemplated, with the aggregate lift of 110 feet; but another scheme has since been adopted, by which the valley in question is flooded and converted into an extensive navigable basin. This will be accomplished by closing the gap at La Flor by a dam 1,800 feet long and 70 feet high, so forming a basin whose surface level will be the same as that of the lake and, in fact, forming a part of it. The basin thus created will be 5.6 miles long on the sailing line, with a depth of water varying from 30 feet to 70 feet, and will have a superficial area of 4,000 acres.

The advantage gained by this plan consists not so much in saving canal excavation for a distance of over 5¼ miles (which is partly offset by the cost of the dam) as in the increased facilities offered to traffic by the large, deep, and safe inner harbor, within 3 miles from the Pacific port, where ships can lie at anchor, or pass each other with safety and freedom when moving in opposite directions. A better control and disposal of the surface drainage is provided by this treatment. Two locks will be placed at the western end of the dam, by whose combined lift the level of the water will be lowered 85 feet, namely, from 110 feet above sea level to 25 feet. From these locks the canal route traverses the valley of Brito, a distance of 1.58 miles, to Lock No. 6, where the last drop of 25 feet is made to sea level. But as a tide of 8 feet must be provided for the lock will have a variable lift of from 21 to 29 feet. From this last lock to the harbor will be about one-half mile of canal, but the prism has been so enlarged as to make that portion of the waterway an extension of the harbor itself.

BRITO.

The only well-founded criticism of the Nicaragua route for an interoceanic canal is the lack of good harbors; but an examination of the existing physical conditions will show that while the construction of ample and safe ports will necessarily involve important and expensive works, yet the cost is not out of proportion to the magnitude and importance of the undertaking, and the engineering problems do not present more serious difficulties than those readily mastered elsewhere for objects less important.

Brito, barely a roadstead, is an indentation of the coast formed by a projecting spur from the coast range. About 1½ miles to the southward another headland juts into the sea. Between lies a cove now filled to about sea level with river silt and sand, but this opening, it is believed, was once an arm of the sea. The Grande traverses this lowland through a narrow channel, and in it the tide ebbs and flows, with a depth at the entrance of about 10 feet at high water. The designs for the creation of this harbor contemplate the construction of two breakwaters—one about 1,000 feet long, projecting from the rocky promontory on the west, and the other 850 feet long and nearly normal to the beach on the east side. (See plan of harbor.) The entrance will be between the jetties, and a considerable deep-water area will be confined, but the main portion of the harbor will be excavated in the alluvial valley of the Grande, the whole forming a broad basin penetrating 3,000 feet from the present shore line and about 4,000 feet from the entrance. Beyond this basin an enlarged section of the canal, about 3,000 feet long, extends to the nearest lock and forms a substantial portion of the harbor itself.

DRAINAGE.

The proposed route of the canal, from the lake nearly to the summit of the Divide Cut, pursues a right line. The Lajas has its source in the hills to the southward, and in its course to the lake intersects the canal line at a distance of 1.25 miles from its mouth. At this point the stream will be diverted through an artificial channel, carried along the south side of the canal and discharged into the lake. A small tributary empties into the Lajas near the point of proposed division of the latter. This brook, called the Guiscoyol, will drain the country to the south as far as the highest point of the line, and the canal follows the general course of this brook. It will be observed that the Rio del Medio, to the north of the canal, drains the country on that side from the vicinity of the Tola Basin to the lake, leaving but a small watershed to be drained into the canal or, if preferred, by a small ditch which may be diverted to the lake. West of the Divide the canal, including the Tola Basin, lies within the watershed of the Grande. With the canal wholly in excavation, no doubt could be entertained as to the necessity of diverting that stream, and careful surveys have been made with that object in view. It was found that to make a diversion channel on the south bank of the Grande would be a work involving some difficulties and heavy expense. A safer, less expensive, and far more satisfactory plan was found to be the diversion of the stream into the Juan Davila, a tributary of the Lajas, and through the latter into the lake, and a careful location has been made to that end. (See plan of western division.) The plan requires the construction of a dam near "El Carmen," and the opening of a canal of diversion from above the dam, through the valley of Jobite and the water course Cumalcagua to the Davila, beyond which no other work will be needed. With the adoption of the basin plan, however, the additional expense demanded by this work seems to be of doubtful expediency. With a large reservoir acting as equalizer of floods, possessing ample facility for discharging the surplus waters over a weir in connection with the dam, through the lock culverts capable of discharging 5,000 cubic feet per second, and through the canal itself eastward into the lake, it does not seem that any injurious results need be feared by receiving the waters of the upper Grande into the basin, especially as the extraordinary floods, which seldom occur, are of but brief duration; and, except at such times, the flow of the stream is insignificant, while for nine months in the year it is nil. The problem, in any case, admits of a practical and satisfactory solution, and perfect immunity from all danger can be secured by the expenditure of, say, $1,500,000. From the Tola Basin to the harbor the canal traverses a flat valley, with no water course to provide for.

THE RIVER SAN JUAN.

From the lake eastward this river will be made navigable for a distance of 64.5 miles by the erection of a dam at Ochoa, and by dredging for the first 28 miles below the lake. Rock blasting will also be needed for a short distance at Toro rapids. The dam at Ochoa will there raise the water 56 feet. It will be 1,250 feet on the crest and 1,900 feet between abutments, with a maximum height of 70 feet. The river in its natural condition from the lake to the Atlantic, a distance of 119 miles by its course, has an average fall of 11 inches per mile, but this slope is not uniform. There are rapids at Toro, Castillo, and Machuca, with an aggregate fall of about 20 feet in a total distance, for the three, of not more than 2½ miles, the fall at Castillo being 4½ feet in a distance of 1,000 feet. On the other hand, between the lake and Toro, and for 15 miles below Machuca, the fall is not more than 1 inch per mile. Two rapids, where the first rock ledge across the river is met with, is the natural weir which maintains the present lake level, the crest being 9 feet above the proposed bottom of the navigable channel. At Castillo, where the ledge is 7 feet lower, 3 feet of rock excavation for a short distance will be needed; and over the present Machuca rapids, 12 miles below, the depth of water as raised by the dam will be not less than 34 feet. Between the lake and Toro dredging to an average depth of 4½ feet will be required throughout an aggregate distance of 24 miles, the material to be removed being gravel, clay, and loose stones. Below Toro no excavation will be needed in the bed of the river, except at the ledge at Castillo. Between the rapids the depth of water attained will vary from 30 to 50 feet, and from Machuca to the dam from 60 to 130 feet. The width of the navigable channel, where no excavation is required, will average 1,000 feet, and, in excavation, 125 feet at the bottom. The surface width will at no point be less than 1,200 feet, expanding in places to 2,500 between the banks, and in the flooded adjacent valleys to 1 mile or more. A fall of three-fourths of an inch to the mile has been allowed from the lake to the dam as the necessary slope to discharge the surplus waters. Consequently, the level of the river at the dam is estimated at 106 feet above sea level, or 4 feet below the lake. For the purpose of navigation, however, that portion of the river may be regarded as an extension of the lake, in which the maximum current will probably never exceed one-half mile an hour.

THE SAN CARLOS.

A short distance above the dam the river San Carlos debouches into the San Juan from the south. This stream drains a large area in Costa Rica, and possesses in marked degree the general characteristics of a tropical torrential river, namely, extreme fluctuations in volume from a nearly dry bed, with barely enough water to float a canoe, to a discharge of possibly 3,000 cubic feet per second. Its upper channel and tributaries, confined by high banks and flowing from mountain slopes, gradually broaden and flatten as they approach the lowlands near the San Juan, and the flanking hills recede from the banks, so that for a few miles above the confluence the San Carlos flows through a wide valley, elevated but a few feet above the bed of the stream. This valley will be flooded to the same level as the San Juan (106 feet), and thus converted into a large basin or artificial lake, constituting a part of the summit level of the canal, navigable for some 20 miles toward the Costa Rica capital. The San Carlos will discharge into this basin or artificial lake at a locality some 20 miles distant from the nearest point of the canal navigation. The San Carlos is the only sand-bearing stream emptying into the waters of the canal. Discharging its waters into a basin of still water, it will deposit all the heavier sand and silt now brought from the highlands by the rapid current 20 miles from the canal line. The lighter material held in suspension will be carried along with the slowly moving current, which will always seek the nearest outlet, and be discharged over the vast weirs to be built in the confining ridge several miles south of the San Juan, and will never reach the channel of the latter stream. The lower part of the valley of the San Carlos will be flooded to a width of from 1 to 2 miles, and to a depth of 60 feet. It will require a long term of years to fill this basin so as to encroach on the canal navigation. When that time does come, the San Carlos waters can, if desired, be diverted entirely by throwing an embankment across the valley and discharging the waters over the weirs previously built, and through existing water courses in the San Juan far below Ochoa.

The confining ridge to the east of the valley extends from the south abutment of the proposed dam in a southerly direction for a distance of 10 miles to the foot of the high mountains of the interior of Costa Rica. There are, however, several depressions in which the ground falls below the contour 114, adopted as top of the confining barrier. These gaps will be closed by embankments, 7 of which will be built wholly above the normal water level in the basin, 11 will have an average height of 21 feet, and 2 of 50 feet, with an aggregate base length of 130 feet, the total length of embankments on crest being 5,893 feet.

THE SAN FRANCISCO.

The canal, as it leaves the river channel a short distance above the Ochoa Dam, is located in the lower valley of Machado Creek. Continuing easterly, it will cross the ridge dividing the valley of the Machado from a swampy region known as Florida Lagoon. It crosses the latter, and then, by a short cut, enters the valley of the San Francisco; and, skirting some foothills to the south, it enters the valley of the Chanchos, follows this stream to its junction with the Limpio, and thence via the valley of the latter to the foot of the dividing ridge. An examination of the plan will be necessary to a clear idea of the topographical conditions existing in this region. It has required much time, labor, and perseverance to develop this topography, and the most careful study to make profitable use of the information thus acquired.

It will be observed that the canal traverses four adjacent valleys. The Florida Lagoon drains into the basin of the San Juan by a small water course, the Danta; the San Francisco Valley by the stream of the same name, and the Limpio and Chanchos by the brook Chanchos, tributary of the San Francisco, the latter, as well as the Danta and Machado, being tributaries of the San Juan. All these valleys are to be converted into large, deep, navigable basins by extending through them the summit level from Ochoa. Their outlets must therefore be closed by embankments; and the foothills, wherever their crests fall below the contour 114, must be raised to that level. The main embankments will have to sustain a water pressure of about 60 feet, the level of the valleys being about 46 feet above the sea. Six embankments will have an aggregate base length of 3,440 feet, and on the crest, of 13,685 feet. The embankments to close gaps in the chain vary considerably in height. Many of them are wholly above the ordinary water level in the basin—i. e., from 1 to 8 feet high—while other gaps require embankments of much greater height. They are 61 in number, with a total length on the crest of 17,835 feet. (See profile showing development of the San Francisco embankment line.)

Several important advantages are gained by this treatment. The total length of basin created is 11.267 miles, of which 8.697 miles will have a water depth varying from 30 to 60 feet. In other words, of the 12.50 miles from the bank of the river San Juan to the deep cut to the eastward of this section, but 1.233 miles will be wholly and 2.570 miles partly in excavation. The economy, however, is not confined to the saving in excavation, against which must, of course, be charged the cost of the embankments, but is principally in the enormous saving in the deep rock excavation following, and in the valley of the Deseado beyond, by carrying the summit level through into the valley of the stream. The increased cost to result from a plan contemplating a much lower level would have been so great as to seriously handicap the undertaking financially. The gain in facilities of navigating and maintaining the canal is also important. Through wide and deep basins vessels can move at full speed, lie at anchor, or pass each other at all points, while in the restricted channel the position and speed of ships must conform to rigid regulations. The problem of drainage also admits of a more favorable solution. A low, level route from Ochoa to the Atlantic would be longer by about 12 miles, and wholly in excavation. In order to avoid the high ridges and projecting spurs, it must keep close to the banks of, and be but a little elevated above, the San Juan. The canal would therefore be in constant danger of destruction—on the south by the river floods, and on the north by the accumulated drainage of an extensive watershed, presenting at all points complicated engineering problems of most difficult solution. By the high-level plan, the largest portion of that watershed is eliminated; and, of the balance yet affecting the canal, a large area is converted into extensive reservoirs, from which the surplus waters can, without difficulty, be discharged over waste weirs on the confining ridges into the low valley on the south, and through the numerous water courses traversing the same into the San Juan.

THE EASTERN DIVIDE CUT.

Proceeding eastward, the route, on leaving the basin, cuts across a narrow neck of the intervening ridge, which is a spur of the main Cordillera bounding the San Juan watershed to the north. The topographical conditions here are remarkable and extremely favorable.

This ridge, as a broad mass of hills, extends on the south to the banks of the river San Juan, often rising to elevations of 1,500 feet, and on the north it merges into the main Cordillera; but at the point selected the spur is nearly divided on the west by the valley of the Chanchos and Limpio, and on the east by that of the Deseado. It will be observed that the axes of these two valleys lie on a generally direct line between Ochoa and Greytown, and that their floors are at about the same level.

The ridge is thus greatly contracted; and here is also the lowest gap in the range for many miles on either flank, its highest point being about 299 feet above sea level. The cut through this pass will be 2.91 miles long, with an average depth to the canal bottom of 141 feet; but at one point projecting a spur must be severed that requires a maximum depth of cut of 328 feet. The summit or lake level is carried through this excavation and 3.08 miles beyond into the valley of the Deseado.

THE DESEADO.

At this point the valley is spanned by a dam 70 feet high and 1,050 feet long, which, together with several small embankments in the gaps of the ridge, aggregating in length 5,800 feet and having an average height of 20 feet, incloses a basin over 3 miles long, in which a depth of from 30 to 70 feet is obtained without excavation for a distance of 2.60 miles. The summit level, therefore, stretches from the upper lock on the Pacific slope to this point, a total distance of 154 miles, or from within 2¼ miles of the Pacific to within 12¾ miles of the Atlantic.

The upper lock in the eastern slope is located close to this dam. It will drop the level, 45 feet, into another basin formed by a second dam, 43 feet high and 820 feet long, and five embankments with total lengths of 1,763 feet by about 20 feet high, to close depressions in the confining ridges. The length of this basin is 1.95 miles, the water level 61 feet above datum, and the depth 30 feet or over. By Lock No. 2, at the lower end of the second basin, the water level is again lowered 30 feet into a third basin extending for a distance of 1.25 miles to Lock No. 1. By connecting this last lock with the flanking hills by ten small embankments, the lower section of the valley is partially flooded and the excavation materially reduced thereby. Lock No. 1 drops the canal 31 feet to sea level. From this point to the harbor of Greytown (San Juan del Norte), a distance of 9.30 miles, the canal traverses an alluvial sandy and swampy plain, but little elevated above the sea, with no features deserving special mention.

THE PORT OF GREYTOWN.

The harbor of Greytown some thirty years ago was yet a good and safe port, with an inner bay of about 500 acres area, with from 20 to 30 feet of water inclosed from the sea by a narrow sand spit extending from the main shore on the east to within a few hundred feet of the mainland to the west. The westerly advance of the spit by the shifting sand, under the influence of the northeast winds and waves, had been gradually contracting the entrance for a long period, so that at the time referred to the channel was already quite narrow, with but 25 feet depth of water opposite the extremity of the spit or "hook." Nothing being done to check its progress, the spit continued to encroach upon the inlet, and about 1860 the harbor became a lagoon, separated by a narrow sand bank from the sea. After long-continued observations and investigations, and due consideration of experience gained elsewhere in analogous conditions, the following plan has been adopted for the restoration of the harbor:

To build a jetty, perpendicularly to the shore line, projecting seaward about 3,000 feet to the 6-fathom curve, and dredging under the lee of this breakwater an entrance into the lagoon, which will also be deepened over an area of 200 acres to the uniform depth of 30 feet. The shifting sands, arrested by the jetty, will gather in the east angle formed by it and the coast, will cause a gradual advance seaward of the new shore line, and in the course of time shoaling at the end of the pier, with tendency to move around and form a new bank across the entrance. This can be avoided by short extensions of the jetty from time to time as may be required, until the new coast line on the east becomes, in its general direction, perpendicular to the prevailing northeast winds. No further change on the coast need then be apprehended, and the permanent restoration of the harbor will be accomplished.

The breakwater is to be built of "pierre perdue," the stone to be brought by rail from the Divide Cut. But in order to start the work, pending the construction of the railroad as far as the Divide, and the beginning of active operations there, it was decided to build the shore end of the pier of a creosoted timber frame filled with fascines and rock, or concrete blocks, leaving it to the shifting sands to fill the voids and form a compact structure. It was expected by this means to afford enough protection to permit the opening of a sufficient entrance channel, which was imperatively demanded for the safe and economical landing of the stores and plant necessary for commencing the main work on the canal. The wisdom of this plan is shown by the results obtained, surpassing the most sanguine expectations. By the time the pier had been extended 600 feet into the sea, and without any assistance by dredging, a channel with 8 feet of water was obtained, and a short time later vessels drawing 12 to 15 feet of water had no difficulty in entering the inner bay. The first 1,000 feet of the jetty have already been thus built, and it is expected that the woodwork will soon be protected by stone from the excavation, and the work thus made permanent. It is proposed to dredge the entrance channel to a depth of 30 feet, with a bottom width of 500 feet, increasing gradually to the 34-foot curve opposite the head of the breakwater.

RAINFALL.

The total annual rainfall in Greytown in 1890 was 296.94 inches; in 1891, 214.27 inches, and in 1892, 291.15 inches. The maximum rainfall recorded is about 6 inches in twenty-four hours. The amount of precipitation decreases rapidly from the Atlantic coast to Lake Nicaragua. Records kept in 1890 at Greytown and at the foot of the Eastern Divide, about 10 miles inland, show a decrease of 34 per cent.

Records kept at Rivas, west of Lake Nicaragua and 5 miles from the canal line, from 1880 to 1889, show a maximum annual rainfall of 87.21 inches in 1886 and a minimum of 34.54 inches in 1885. Practically no rain falls from November to May on the west side, while on the Atlantic slope more or less rain falls every month, but from February to May it is comparatively dry. Ample provision has been made for the disposal of the surplus water in designing the works.

DRAINAGE.

The problem of disposing of the surplus waters in that portion of the route from the basin of the San Juan to the lower Deseado will now be considered. The flow of the San Juan at Ochoa at high flood in both the San Carlos and San Juan has been found by careful gauging to be 42,000 cubic feet per second. The river is known to have risen somewhat higher, but, as no gauging was made at the time, the above figures will be increased by 50 per cent, making the possible maximum flow 63,000 cubic feet per second, of which not less than two-thirds would probably come from the San Carlos, the upper San Juan not being subject to great alternatives of flow. The combined basins of the San Francisco region have a watershed of about 65,000 square miles, and assuming a maximum rainfall of 12 inches in twenty-four hours—about twice the greatest rainfall—there will result a possible discharge of 21,000 cubic feet per second from the San Francisco basins. The watershed of the upper Deseado Basin is about 12 square miles, which on the above basis will yield a discharge of, say, 4,000 cubic feet per second, making a total of 88,000 cubic feet per second, for the discharge of which provision must be made. No deduction will be made on account of consumption in lockage, which may reach 1,500 cubic feet per second, nor for leakage, which may take up a much larger amount. Considerable allowance should, however, be made for the new conditions established by the introduction of large reservoirs, which will hold the waters back and regulate their gradual discharge in lieu of rapidly inclined streams fed by precipitous watersheds, which collect and discharge the rain water almost as fast as it is precipitated. Yet all these considerations will be for the present kept in reserve as a large margin of safety.

Provisions will first be made for the discharge of 63,000 cubic feet per second from the basin of the San Juan. In doing so care will be taken to prevent any large discharge at any one point, which is likely to cause serious accidents by undermining and scouring or undue sudden changes in the level of the water. A large overflow in the vicinity of a dam will be avoided, and in the San Juan Basin the current should be directed for its outlet toward the southern end of the San Carlos Basin, or, at any rate, the water of that river must be excluded from the navigable channel of the canal as much as possible. This can be done by placing three or four weirs, with an aggregate length of crest of 1,200 feet, as far south on the eastern confining ridge as practicable. Their discharge will be led off into the swamps and lagoons immediately to the east of the ridge, and thence by Curena Creek into the San Juan about 5 miles below Ochoa Dam. In this manner the sediment-laden waters of the San Carlos will be discharged directly, before reaching the San Juan, and the heavy deposits of silt so excluded from the valley. The crest of the weirs will be placed 18 inches below the crest of the Ochoa Dam, and in ordinary conditions the surplus waters will escape through these weirs, which will be the lowest outlets.

It is proposed to place the crests of the Ochoa Dam (1,250 feet long) at 105 feet above datum, or 1 foot below the water level of the canal at that point. The discharge under varying conditions of level will then be approximately as follows:

At normal level, 106 feet	cubic feet per second	2,900
At 110 feet level	do	32,000
At 111 feet level	do	42,500

The crests of the weirs on the ridge will be placed at 103.5 feet above datum, and their discharge for the total length of 1,200 feet may be estimated as follows:

At normal level	cubic feet per second	11,300
At 110 feet level	do	47,700
At 111 feet level	do	65,300

The combined discharge over the dam and weirs at normal, 110, and 111 foot levels will therefore be, respectively, 14,200, 79,900, and 107,800 cubic feet per second; that is to say, the maximum floods will be discharged before the level of the basin rises 4 feet above normal. In fact, it is unlikely that the level will ever rise nearly to that height as assumed, as a rise in the San Carlos Basin will have the effect of checking the flow of the San Juan, and possibly reverse the current temporarily toward the lake. For the drainage of the San Francisco Basin, three weirs, with a total length of overflow of 600 feet, will be built on the bordering ridge, so placed as to carry off the surplus water without producing injurious currents in the basins.

By placing the crests at the uniform level of 104 feet the discharge will be:

At normal level	cubic feet per second	4,100
At 110 feet level	do	21,200
At 111 feet level	do	26,700

In the upper Deseado Basin 300 feet of overflow at 104 foot level will give the following discharges in round numbers:

At normal level	cubic feet per second	2,000
At 110 feet level	do	10,600
At 111 feet level	do	13,300

These provisions are more than ample to meet the maximum requirements in each of the basins without causing undue current in the short cuts connecting them.

The possible accumulated discharge from the summit level at a given time may therefore be put down as follows:

At normal level	cubic feet per second	20,300
At 110 feet level	do	111,700
At 111 feet level	do	147,800

It may be confidently asserted that the second figures will never be reached, and that the crest of the Ochoa Dam may be raised above the water level in the San Juan, and yet the highest floods will not reach the 110-foot contour, the weirs being ample to so limit it.

Other provisions, however, have been made with the view to aid in construction, to facilitate repairs, and, as additional precautions, to meet possible contingencies, especially in the series of embankments in the San Francisco Ridge, which it is frankly admitted is the weakest feature in the whole route. These safeguards consist of a guard gate to be placed in the cut connecting the valley of the Machado with Florida Lagoon, by which the flow of water from the San Juan toward the San Francisco Basin can be shut off, and two antifriction gate sluices, one in the San Francisco Ridge and the other in that of the upper Deseado, by which the water in these basins can be drained off to 30 feet below normal level, thus relieving the embankments of that pressure during construction and enabling repairs in the cuts and embankments afterwards.

These sluices have openings of 25 by 20 feet, with the lower sill 30 feet below the normal level. Their capacity of discharge will vary with the head, being 12,500 cubic feet per second for each when the water stands at the 106-foot contour.

By these means 25,000 cubic feet per second additional can be drawn from the summit level, regardless of the lock culverts, through which 4,500 cubic feet per second more can be spilled.

The middle Deseado Basin will be drained by weirs, with 400 feet length of crest, which will be 2 feet below ordinary level, and capable of discharging from 2,700 to 14,100 cubic feet per second at 61 and 65-foot levels, respectively.

In the lower basin 500 feet lengths of weir are provided for, the estimated discharge being from 3,400 to 17,000 cubic feet per second, respectively, at normal and 35-foot levels. Beyond the lower basin the surplus waters are diverted by a short cut into the San Juanillo, and through the latter into the San Juan to the sea.

From Lock No. 1 to the harbor no special provision need be made to drain the adjacent country. The canal traverses a swamp with numerous natural drains, and, being flanked on both sides by high embankments made by the earth spoil, it needs no additional protection.

OTHER CANALS.

It will be interesting to compare the sections first proposed for the Nicaragua Canal with those of other ship canals existing and proposed:

Canal.	Depth.	Surface width.	Bottom width.	Area of prism.	Length.	Remarks.
	Feet.	*Feet.*	*Feet.*	*Sq. ft.*	*Miles.*	
Suez:						
Original dimensions, earth	26.20	328	72.2	4,170	100	Existing.
Enlarged dimensions, earth	27.90	328	112.9	5,412		Enlarging.
Nicaragua:						
Rock section	30	184	80	2,400	7.8	
Earth section	30	184	80	3,960	9.7	Proposed.
Do	28	288	120	5,212	9.8	
Manchester:						
Earth section	26	172	120	3,796	35	Nearly completed.
Rock section	26	130	120	3,250		
Amsterdam, earth section	23	186	88.5	3,156	15.5	Existing.
Corinth, rock section	26	77.4	72.2	1,945	4	Nearly completed.
Panama:						
Earth section	27.80	160	72.2	3,227	47	Proposed.
Rock section	29.50	91.8	78.7	2,513		
North Sea and Baltic, earth	28	197	85	3,930	60	Constructing.
Bruges	26.26	223	65.6	3,789	6.5	Proposed.

N. B.—The dimensions given are taken at mean low water.

The Suez Canal cost $100,000,000, and in 1883 passed 3,307 vessels, with net tonnage of 5,775,861 tons, before its enlargement was undertaken. This was accomplished, notwithstanding the fact that the channel was so narrow that sidings had to be constructed into which one vessel had to be placed while another was passing.

In the Nicaragua Canal the narrow rock sections are divided into two and the east sections into many short lengths, separated by broad and deep basins, through which the largest vessels can steam and meet others without slacking speed.

It was originally planned that some sections of the canal in earth would be 80 feet in bottom width, with side slopes of 1½ to 1 and in the rock cuts with vertical sides. This would accommodate the traffic for several years, and then the areas in cross section could be increased out of the earnings, as at Suez, but at a greater ultimate cost. It has been decided to make provision in the designs for the ultimate requirements, and the following table shows the length of the different sections of the canal in excavation in the lake, the river San Juan, and through the basins, and also the dimensions of prism for the same as now proposed:

	Length (miles).		Remarks.
Canal in excavation:			
East side	14.870	....	
West side	11.160	....	
Six locks, both sides	.759	26.789	Total canal in excavation.
Basins of the Deseado	4.848	....	
Basin of the San Francisco	11.267	....	
Basin of Tola	5.504	21.619	Total length of basins.
River San Juan	64,540	....	
Lake Nicaragua	56.500	121.040	
From the Atlantic to the Pacific	....	169.448	Total length of route.

The dimensions of the canal in excavation in the several sections are as follows:

	Length.	Width.		Depth.	Slope.	Area of prism.
		Top.	Bottom.			
	Miles.	*Feet.*	*Feet.*	*Feet.*		*Sq. fet.*
From Greytown to Lock No. 1	9.297	288	120	28	3 to 1	5,712
From Lock No. 1 to Eastern Divide Cut	1.423	210	120	30	1½ to 1	4,950
Eastern Divide Cut	2.917	100	100	30	0	3,000
In eastern San Francisco Basin	1.233	210	120	30	1½ to 1	4,950
From lake to Western Divide Cut	1.565	210	120	30	1½ to 1	4,950
Western Divide Cut	4.294	100	100	30	0	3,000
Western Divide Cut to Tola Basin	2.519	210	120	30	1½ to 1	4,950
Lock No. 5 to Lock No. 6	1.582	210	120	30	1½ to 1	4,950
Lock No. 6 to Brito Harbor	.570	(*)	(*)	30	2 to 1	(*)
River San Juan where dredged	27.500	(*)	125	†28	(‡)	(‡)
Lake where dredged	14.250	(*)	150	30	(‡)	(‡)

* Variable. † Mean. ‡ Undetermined.

THE EXCAVATIONS.

The character of the material to be removed, both wet and dry, has been accurately determined on the whole route by numerous borings penetrating to the bottom of the canal and on the site of the dams, embankments, and locks, to the depth required to ascertain in each case the nature of the foundations. In the harbor of Greytown and its approaches clean, sharp sand is the only material met with. From the harbor to Lock No. 1 and through Benard Lagoon the materials are sand and sandy clay, underlying a thin, loamy stratum and decomposed organic matter, and from the lagoon to the lower lock, stiff clay. The harbor and this sea-level portion of the canal will be made with the floating dredge. Slopes of 3 horizontal to 1 vertical have been allowed in the estimates; but past experience gained in dredging by the company in the first mile of canal shows that the material stands perfectly for several months at a much less inclination, and in the excavation for the railroad through the stiff, tenacious clay predominating in this region the material stands nearly vertical. However, slopes of 1½ to 1 have been estimated for. From the lower lock to the Divide Cut this hard clay, with occasional bowlders, is the only material found by the boring tool on the axis of the canal throughout, and also at the site of the three locks and the embankment. This clay is impervious to water, and has a large sustaining power, so that no apprehension is felt as to the character of the foundations. In the deep cut the geological formation is clay, overlying solid volcanic rock. (See geological profile.) Diamond-drill borings have been taken along the whole length of the cut to the bottom of the canal at intervals of about 1,000 feet; and the cores brought up settle beyond doubt the character of the material to be removed, and dispel all apprehension that this cut might be a repetition of the disastrous experience in the great Culebra cut at Panama. The slope allowed in clay is 1½ to 1 and in rock ¼ to 1 to the level of the water, and below that point vertical. In fact, there is no good reason why the whole rock excavation should not be made with vertical sides. In the Corinth Canal, where the excavation is longer and deeper and the rock less homogeneous and softer, a slope of $\frac{1}{10}$ to 1 has been carried down to the water level, and the sides do not crumble or slide. From the Divide to Ochoa homogeneous clay has been found at all points; and, as shown in the preceding table, the standard section in soft material has been adopted throughout. At the site of the Ochoa Dam gravel, clay, and rock, in the order named, are shown by the borings.

EMBANKMENTS AND DAMS.

The embankments in the valleys and on the crest of the confining ridges are proposed to be made water-tight of the clay, which is of excellent quality for this purpose, prevailing everywhere in those hills and valleys, but taken principally from the excavations. The embankments rise 8 feet above the water surface, with top widths of 12 feet if not over 8 feet high, 15 feet if not over 15 feet in height, and 20 feet for heights above 15 feet. Water slope, 3 to 1; dry slope, 2½ to 1. Top and water slopes to be paved with 2 feet of well-laid stones. Of these embankments, two in the valley of the Deseado and six in the San Francisco Basin, will be of considerable height, especially the latter, as the surface earth will be removed to form depths so as to insure a solid and secure foundation.

The maximum water pressure against the Deseado dams will be 45 feet, and in the San Francisco but little more than 60 feet, as water always lies on the surface, or but little below it, in the valleys. These embankments, intended to impound so large a volume of water, are important works, and in their construction sound judgment and great care must be exercised; but they present no more serious difficulties than have already been successfully met at many other localities. In a paper like this details of construction, which belong entirely to the specifications for the works, can not be treated at length; but it may be proper to remark that with good bottom to build upon and excellent material of construction and with proper execution, no apprehension need be felt for the safety of works. The small embankments are numerous, it is true, but they deserve no special mention. They constitute a number of such ordinary jobs as the practical engineer is constantly called upon to handle.

The Ochoa and Tola dams are the keys controlling this great problem at the east and west ends of the summit level, and should not be passed without special notice, particularly so the former, in which a novel method of construction is contemplated. This work has been for years the subject of long study and careful consideration. The diversion of the river San Juan is well nigh impossible, and construction by the usual methods, with either cut stone or concrete, of so important a work in opposition to the mighty power of the stream is a problem involving the most serious difficulties. It was at first proposed to build a stone dam upon a series of arches supported by tiers starting from the foundation, through which the river waters could flow freely during the construction of the main part of the structure, these openings to be closed by gates in the upper side when the upper part of the dam, its approaches and aprons, were completed, and then to be filled with masonry from the lower side while the water was rising in the basin. This was, perhaps, as a practical solution, probably the best under the circumstances for that style of dam, but its execution would be tedious, difficult, and expensive, and there was to be always present an element of doubt not easy to eliminate as to the final success. The building of the foundations and pilaster for the support of the arches in constant contention with the whole river would be a most difficult undertaking, in which the items of time and cost would remain unknown quantities to its completion. Another idea has since been suggested, which seems to embody simplicity, economy, and safety. It consists in dumping from an aerial suspension conveyor large and small material, properly assorted, across the river from bank to bank until a barrier is created sufficiently high and strong to arrest the flow and hold the waters at the required level, the body of the dam to be made up of large blocks of stone, weighing from 1 to 10 tons, and smaller material to fill the voids. Its base will be quite broad, as compared with the height, probably from 400 to 500 feet between the foot of the upstream slope and the end of the apron. The top is estimated 30 feet wide, the rock upstream slope 1 to 1, and the apron or downstream slope 4 to 1, with the lower portion flattening down to 5 or 6 to 1.

On the upstream side small material, such as stone, fragments of gravel, clay, etc., selected as circumstances may require, will be deposited as the work advances, in sufficient quantity, as tight as wanted. It is not expected or even desirable to have a water-tight structure, the object sought being simply to oppose such an obstruction to the river as may be necessary to hold the waters at the required level. The minimum flow of the river is about ten times the water needed for working the canal. Consequently, nine-tenths of it can be wasted with advantage. That the dam will eventually become tight there can be no doubt, as the small drifts and detritus forced in by the current will gradually fill the voids and consolidate the structure.

The method of construction will be quite simple. After protecting the abutments against possible erosion, large pieces of rock will be dumped in the bed of the stream from three or four cableways spanning the valley. The material should be distributed uniformly over the area under the main portion of the dam, commencing upstream, and keeping up, as nearly as possible, an even level. Scouring will soon cause settling of the blocks into firmer soil, the upper level in the meantime being constantly raised by depositing more stone, while the small material is being forced by the current into the voids, and the overflow dislodging and rearranging the unstable blocks until they reach a final resting place. This process to be continued until the resistance at the bottom becomes so great as to check scouring due to maximum pressure, when the dam will be carried up to the desired level. The river, in the meantime running over the mound, will readjust the material in and adapt the apron to the necessary conditions of stability to withstand the effect of the fall and carry off the water safely. If the dam is then raised so as to shut off a whole or the largest part of the river flow, which can by that time be discharged over the waste weirs, the structure will be permanent. If the river is not able to prevent the completion of this work, having, on the contrary, greatly contributed to its construction by a better distribution and consolidation of the material, now that the waters are diverted to another outlet, no fear need be entertained as to injury from that source. There may be some settlement and final readjustment of the component parts for some time after completion, but that can be easily remedied by depositing more material where needed. It is believed that this dam will be safer, as it is by far more economical, than a stone dam. An earthquake might cause serious damage to a masonry dam, but it can do no harm to this. On the contrary, it may add to its consolidation by bringing the parts in closer contact. There are no cemented joints to be opened, and a seismic disturbance would have a tendency to compact rather than to disintegrate the large mass. The rock for the dam will be brought by rail from the Divide, and delivered immediately under the wire cables, each one of which will be capable of handling and depositing about 1,000 tons in ten hours. Consequently, the work can be completed in from four to five years, and, if need be, in less time.

DEEPENING THE RIVER BED.

Another work of some magnitude is rock blasting under water at Castillo and Toro Rapids, amounting to about 400,000 cubic yards, the quantity to be determined by the side slopes found necessary. This work can be more ecomically done before the water is raised to the assumed summit level, but not before the lower section of the river has been raised by the Ochoa Dam to the level of the upper rapids. Otherwise, the excavation in the upper rock ledge might cause an undue fall in the lake level, which would greatly interfere with navigation and the progress of the works in river and lake. This work presents no unusual difficulties, and the estimated cost of $5 per cubic yard will more than cover the cost. Above Toro Rapids dredging will be needed in the bed of the river for about 24 miles. The average depth is 4½ feet. The material is mud, clay, silt, and some loose bowlders.

LAKE DREDGING AND PIERS.

At the east side of the lake dredging will be needed for about 14 miles from the outlet. The material is soft mud. The bottom width of the navigable channel here proposed is 150 feet, and the slopes three to one. That side of the lake being sheltered from the prevailing northeast winds, no provisions are needed to protect the channel.

On the west side rock excavation in the lake, amounting to 176,000 cubic yards, is estimated for, also at $5 per cubic yard. This shore of the lake is exposed to the prevailing winds and waves, and the canal entrance must be protected by two piers projecting to deep water in the lake. They are proposed of crib, for which the native hard wood is admirably suited, and ought to be filled with stone from the excavations.

THE WESTERN DIVIDE.

From the lake shore to the Tola Basin the excavation is in rock and clay, rock predominating through the Divide and clay in the valley of the Grande. Borings have been made from the bottom of the canal all the way to the sea, and the amount and character of the material to be removed accurately ascertained. From the basin to Lock No. 6 clay is the material met with, and in the harbor area principally sand, with some mud and clay in the upper section.

THE LA FLOR DAM.

Numerous deep borings have been lately made at the site of La Flor Dam, the results showing the solid rock ledge to lie much deeper than the first earth auger borings indicated, and that the original plans for that work must be materially modified to adapt them to existing conditions.

It was contemplated to build this dam of rock fill, on the same principle adopted at Ochoa; but the great depths of soft earth overlying the rock ledge, reaching in places to 96 feet below the valley, renders that plan inapplicable to this case, especially as here, unlike the San Juan, there is no large flow of water to assist in scouring the soft soil and in consolidating the fill. A dam with solid masonry core and earth slope is now proposed, spanning the valley with a length of about 2,000 feet, an extreme depth for 1,000 feet length of 170 feet from crest to foundation of core, of which 70 feet will be above ground, and in addition to core walls aggregating about 500 feet in length, penetrating the abutment hills to the rock ledge. Locks Nos. 4 and 5 will also rest in this bed of rock, forming part of the dam abutment, and connecting with the core wall at its western end. A waste weir, about 300 feet long, will be cut on the east side for the discharge of surplus water into the lower bed of the Grande. All this comprises a very important piece of work; but with good rock foundations and suitable material at hand, although its cost will be proportional to the magnitude of the enterprise, there is nothing to intimate serious engineering obstacles. Concrete will be used for the core walls and locks, the rock to be obtained from the Divide Cut. The earth for the puddle fillings and embankments can be had from the canal excavation or from the valley in the vicinity of the works.

THE LOCKS.

The locks are to be 650 feet long by 80 feet wide in the chamber. The lifts, as now proposed, will vary from 30 to 45 feet; and a change is under consideration by which the lift of Lock No. 3 may be reduced to 40 feet and that of No. 2 increased from 30 to 35 feet. These high-lift locks must not be regarded as necessary features of the project imposed by existing conditions. The gradual descent of the Pacific and Atlantic slopes to sea level after leaving the Divide Cuts, combined with the highly favorable topography of the country traversed by the canal, present many admirable sites for locks, the number of which could be so increased as to greatly diminish all the lifts. Such a plan, however, is not regarded as the best with a view to economy in original construction and future maintenance, or in facility to the traffic through the canal. Of course, the matter of safety is of first consideration; but, with the exercise of proper care and engineering skill, the plans proposed can be successfully carried out. In the proposed plan for a lock canal at Panama, lifts of 36 feet, with a possible maximum of 46 feet at high water, were adopted by the commission; but we can not recall any ship-canal lock in actual operation with lifts approaching these figures. Yet, in working out the problem, the mechanical details, although necessarily of large proportions, have not so far developed any insurmountable difficulties, either in construction or manipulation afterwards. The body of the lock is to be of concrete, with cut stones in the miter sills, the hollow quoins, and such angles as need protection from shocks. The gates will be of steel, to be manipulated by hydraulic machinery, of which we have an admirable example at the St. Marys Falls Canal, where a lock 519 feet long by 80 feet wide, and a lift of 18 feet, is filled in 11 minutes and emptied in 8 minutes, the time consumed in opening or closing the gates more than 40 feet high being but 1¼ minutes. Another lock 800 feet long and 100 feet wide, with 21 feet minimum depth of water over the miter sill, is here under construction, and the time of filling and emptying the chamber will be shortened by enlarging the size of the culverts.

TIME OF LOCKAGE.

The traffic passing through the canal will be limited by the time required for a vessel to pass a lock. In the St. Marys Falls Canal vessels of over 3,000 tons capacity are put through the lock inside of 20 minutes; and the writer has seen the whole operation of opening the lower gates, entrance of the steamer, filling the chamber, opening the upper gates, and exit of the vessel from the lock, inside of 19 minutes. In the Nicaragua Canal the operation of filling the lock and handling the gates will consume no more time, yet 45 minutes have been estimated as the average required for lockage. On that basis, and allowing but one vessel in each operation, the number that can pass the canal in one day is 32, or in one year 11,680. At the average tonnage of vessels using the Suez Canal, these would supply an aggregate of 20,440,000 tons. The traffic through the St. Marys Falls Canal lock in seven months in 1891 was nearly 9,000,000 tons, and in the same time in 1892 it exceeded 11,000,000 tons, or at the rate of 19,000,000 tons annually; and the maximum capacity of the lock has not yet been reached. The vessels taking the Nicaragua route will be much larger than those upon the Great Lakes, and the tonnage per lockage will, consequently, be proportionately greater. For this reason a single system of locks has been proposed at the start; and, when the business requires it, parallel locks can be built and the capacity of the canal doubled. Attention is called to the important feature of having all the locks connected with large basins, which will greatly facilitate the movement and allow the withdrawal of a large volume of water in a short time without injurious current or marked fluctuations of level in the basins. The question of water supply needs but a passing reference, the maximum amount required for the 32 lockages, on the improbable basis of 1 lock full for each operation, namely, 127,400,000 cubic feet, being but one-tenth of the minimum daily discharge of the lake.

TIME OF TRANSIT.

In estimating the time of transit from ocean to ocean, the speed in the excavated sections of the canal has been limited to 5 miles an hour, although in the Suez Canal steamers of 6,000 tons are allowed to move at 6 miles an hour and smaller vessels proceed at the rate of 7 or 8 miles an hour. In the lake and in the greater part of the river San Juan vessels can travel with unrestricted speed, hence:

Estimated time of through transit by steamers.

	h.	m.
26.030 miles of canal, at 5 miles an hour	5	12
21.619 miles in basins, at 7 miles an hour	3	05
64.540 miles river San Juan, at 8 miles an hour	8	04
56.500 miles in lake, at 10 miles an hour	5	39
Six lockages, at 45 minutes each	4	30
Allow for detentions	1	30
Total time of transit	28	00

TRANSPORTATION FACILITIES.

Railroad lines have been projected from Greytown to the river San Juan at Ochoa, a distance of 37 miles, and from the lake to Brito, 18 miles. Of the former distance 12 miles are already finished, from Greytown toward the Divide, and are now in excellent condition and in operation in connection with the canal works. As soon as the rock is reached, the road will be extended across the Greytown Lagoon to the breakwater at the harbor entrance, upon which the rock from the excavation will be brought and dumped directly, as at Galveston, Tex.

PERIOD FOR CONSTRUCTION.

The time in which the canal can be finished will be controlled by the time needed to complete those important works without which the traffic can not be established. It has been pointed out that the Ochoa Dam can be finished in four or five years.

The Tola Dam, the locks, and the harbors can also be done in that time. The Western Divide Cut contains about 11,000,000 cubic yards of rock and earth; but the excavation is about 9 miles long, and the greatest depth but 72 feet, consequently this work is of lesser magnitude than the Eastern Divide, in which a probable total of 12,000,000 yards will have to be extracted and removed from a trench less than 3 miles long at an average depth of 141 feet. It is, therefore, to this latter work that we will have to look for a limitation in estimating the time in which the whole route can be opened to the world's traffic. On the basis of 12,000,000 cubic yards, of which two-thirds will be rock, assuming six years' continuous work, at the rate of ten hours a day, there will be an output of 6,700 cubic yards per day. This amount of material can be lifted and landed on the cars by 22 overhead wire cables at the moderate rate of 300 cubic yards each per day, and can be hauled to the dump or place of destination by 112 train loads of but 120 tons each, or, say, 11 train loads an hour. About one-eighth of this will go as far as Ochoa, for the construction of the dam, and about the same amount for the breakwaters and the locks Nos. 1, 2, and 3. Of the balance, one-half will probably be needed for the embankments in the valleys of the Deseado and San Francisco; and the rest can be deposited in the vicinity of the excavation, but a few hundred yards away. Allowing for repairs, accidents, and other unavoidable delays, it may be estimated that a plant comprising 30 cableways, with attachment and machinery, 50 locomotives, and 1,000 cars will be ample for this work. The above would be a rather heavy traffic to handle, if sent out over the main line, but, distributed as suggested above, with a large portion of it sent off on spur tracks from both sides of the 3 miles of excavations, to be deposited in the numerous ravines and valleys in the vicinity of the work, it does not look unmanageable. But, if need be, work can be carried on without interruption by the aid of electric lights. Therefore, as regards the disposition of material, six years seem to be ample; and as to the work of digging and blasting, it will be admitted that the mind capable of organizing and carrying out the former will have no difficulty in mastering the latter. Consequently, the previous estimate that the canal can be completed in six years after the works are fairly started is adhered to.

On one section 2¼ miles one way of the Manchester Canal, now under construction, the contractor has taken out for two or three months continuously at the rate of 20,000 tons per day in one shift of nine hours. This includes ballasting, loading in wagons, hauling, and depositing. The plant employed consists of 59 locomotives and 1,400 wagons. The contractor has been much restricted and embarrassed in his operations by limited dumping grounds, which would not be the case in Nicaragua.

ESTIMATES.

In estimating the cost of the canal, the following prices per cubic yard have been adopted: Dredging, 20 cents and 30 cents; excavation in earth, 40 cents; excavation in rock, $1.50 and $1.25; excavation under water, $5; embankments, 40 to 70 cents; concrete, $6 to $10; rock fill, 50 cents; breakwater, pierre perdue, $1.50; grubbing and clearing, $100 per acre; railroads, $60,000 and $25,000 per mile; telegraph, $600 per mile. The total cost of the canal is estimated at $65,000,000, inclusive of 25 per cent for contingencies, but exclusive of interest, commissions, and other charges not coming under the cognizance of the engineer, and on the basis that the work will be prosecuted with vigor along the whole line and without intermission.

APPENDIX L.

NICARAGUA CANAL CONSTRUCTION COMPANY.

REPORT OF THE BOARD OF CONSULTING ENGINEERS, MAY 9, 1889.

To the Nicaragua Canal Construction Company.

GENTLEMEN: The undersigned were requested by your letter of January 10, 1889, to examine the plans and estimates prepared by your chief engineer, Mr. A. G. Menocal, for a ship canal between the two oceans at Nicaragua, and to indicate the cost, in their judgment, of constructing a canal along the line proposed and following, in general, the plans of your chief engineer. You also requested an opinion upon the practicability of the canal as now proposed, with due reference to the end in view, namely, the safe and convenient passage of seagoing ships from ocean to ocean. We beg to present the following report:

We have carefully examined the unusually full maps, profiles, borings, samples of materials, etc., which have been prepared and collected under the directions of your chief engineer, and the completeness and excellent form of which reflect credit upon your engineering staff.

We find certain elements of the designs submitted which may probably be advantageously modified. This would, in some cases, reduce, and in others increase, the quantities. It is also altogether likely that some parts of the work may be let at lower, and other parts at higher prices than are estimated. We, however, are disposed to base our conclusions on quantities and prices which should prove sufficient to accomplish it upon the assumption of good and honest management, backed by an ample treasury. We have necessarily borne in mind the fact that the cost of the notable precursors of this canal project, both at Suez and Panama, has greatly exceeded the amount of the original estimates, and that this has been true of many other important works. While this might be, perhaps in a large measure traced to unfortunate management as well as the lack of such careful preliminary studies as have been laid before us in this case, we have nevertheless endeavored to guard against a similar result by a liberal allowance for every apparent contingency.

Acting on this principle, we have not deemed it wise to reduce the quantities or prices of your chief engineer's estimates in any instance, even when it appeared possible that this might prudently be done. His figures are, of course, founded upon a better knowledge of the local conditions than we can now possess. But to the extent to which it has appeared at all doubtful we have liberally increased one or both. Our conclusions are as follows:

The project, as a whole, appears to have comparatively few elements of doubt about it, as contrasted with other works of at all similar magnitude, and we consider it to be unquestionably feasible. The great area of Lake Nicaragua offers immunity from serious floods by regulating flow. Much of the earth excavation and dredging, the rock drilling, and the concrete mixing can be done by mechanical means, to that extent reducing the need of manual labor. The dams and embankments are proposed to be made largely from the immense mass of otherwise useless rock spoil. Under the climatic conditions, as we understand them, an adequate supply of labor should be obtainable. The project in detail consists of the following elements:

First. Of 10 miles on the east end and 0.57 mile on the west end of sea-level canal dredged in from the coast. The borings submitted seem to warrant the opinion that this will be entirely through alluvial deposits, as is also the case in certain parallel river diversions. The samples of material taken from these borings all appear favorable for dredging, and the cost of such dredging can be foreseen with the greater precision, because less influenced by climate, weather, and rates of wages than most other engineering work.

Second. Of a flight of three locks on each end, all within a distance of about 1¼ miles at one end and 2 miles at the other, by which the ascent is made from the sea level to the summit level of 110 feet (this elevation being some 4 feet less on the eastern end to allow for a necessary fall of three-fourths of an inch per mile in the San Juan River). These locks are shown by the borings submitted to be all founded on rock. The proposed size for locks, 650 by 70 by 30 feet deep, seems sufficient for all demands.

Third. Of a very long summit level of 155.98 miles, consisting of four main parts:

(a) The great Divide cuts of 3 and 8 miles in length, respectively, which are shown by the evidence submitted, to consist chiefly of rock, overlaid with a few feet of earth.

(b) The Deseado, San Francisco, Machado, and Tola basins formed by dams, furnish 21.57 miles of slack-water navigation, 18.13 miles of which require no excavation, and the remaining 3.44 miles earth dredging only.

(c) The river San Juan, raised in level by a dam at Ochoa so as to furnish slack-water navigation, and Lake Nicaragua furnish, together, 121 miles of free navigation, of which 36.5 miles require some earth dredging, and 3.83 miles some rock dredging.

(d) An inconsiderable amount (1.63 miles) of canal section in earth, chiefly to connect the San Francisco and Machado basins.

The two great rock cuts are by far the heaviest features of the work. In considering the plans for them and determining the proper amount and cost of work we have felt that every provision should be made to secure permanent slopes and to provide a section suitable for any vessels which can pass the locks. We think that the estimates, as modified by us, will secure these results.

The four great basins present a most admirable feature of the plans. As compared with a restricted canal channel, they facilitate navigation as well as reduce the cost. They are made, as is also the slack-water navigation of the San Juan River, by dams and embankments of considerable extent, none, however, of very great height. The plans submitted provide for forming these dams and embankments chiefly of heavy rock filling, the proximity of the great rock cuts (from which material must otherwise be wasted) to the sites of these dams and embankments facilitating their permanent construction at moderate cost. While we are not ready to say that the details of the plans submitted may not be, in some respects, modified, we regard the estimates adopted as sufficient to attain the results desired, subject to the following contingency:

There is the possible hazard in respect to the San Francisco and other basins, that they may not prove sufficiently retentive, owing either to leakage around the ends or under the bases of the dam and embankments, or to concealed permeable strata beneath the natural surface. We deem this a remote danger, since both the surface and subterranean formations, so far as revealed by borings and by the reports of the observations of reliable men familiar with the locality, are favorable.

For a work of ordinary magnitude we would accept such evidence as ample, but in view of the great area and volume of the basins, we agree that the possibility ought to be covered by the estimate. The probability is great that there are no permeable strata beneath the surface; if they exist they might not necessarily cause leakage, and even if leakage resulted, it would not necessarily do serious harm. Concentrated leakage, if it occurred, might possibly be remedied, and, if it should develop at all, would be likely to occur at an early stage of the work of construction. The worst result to be feared is that it might impel a modification of the original features of the project enforcing a lowering of the water level at certain points, and at an additional cost of about $7,000,000. Under the circumstances, we, out of abundant caution, have deemed it wise and right to make the general contingency of allowance ($14,633,262) large enough, in our opinion, to cover this amount.

The requisite depth in the San Juan River and in Lake Nicaragua is obtained by a considerable amount of dredging, largely of earth, but also with an amount of rock blasting under water, the precise extent and cost of which it is exceptionally difficult to foresee. We have therefore made an allowance for this work.

We have included in the estimates the sum of $1,035,000 for the diversion of the Rio Grande, as it seems proper to provide for the possible necessity of the diversion of this important stream from the canal. We have also included in the estimate the amount named by the chief engineer for the work that may be necessary in the valley of the San Carlos and in the construction of the canal between Lake Managua and Lake Nicaragua, this construction being a requirement of the concession.

The estimates for the harbor improvements at Brito and Greytown we leave unchanged. It appears probable that the amounts estimated may prove ample for all requirements other than gradual enlargement of basin areas, but whether so or not (and it is always extremely difficult to anticipate with certainty what may be the ultimate requirements for work of this class), we do not see the necessity in this work, as we do in the canal proper, for the endeavor to provide at the outset for all future demands of commerce. Sufficient expenditure prior to the opening of the canal to meet reasonable requirements for the first year or two after opening is all that we have taken into consideration in our estimates. The canal once opened, adequate harbors can certainly be provided at a moderate percentage on the total cost of the canal, even should the sum herein estimated for harbors and contingencies prove insufficient. We must not be understood as implying by this statement, however, that we now see reason to fear that the present estimate for harbor work will probably prove inadequate. Such is not the fact.

It may not be regarded as improper to mention also that while the cuts, locks, dams, etc., should be completed for the full depths at the outset, something like one-fifth of the total amount of the estimate is for dredging and earth excavation under water, which is not required to afford 20 feet draft, and which can be completed with little or no disadvantage after the canal has been so far constructed as to pass vessels of that draft, making it possible—if found advisable—to open the canal for 20 feet draft for about four-fifths of the final cost.

Our estimate, which is intended to represent the maximum sum which the canal ought to cost, assuming, as aforesaid, integrity, good management, and no interruption of work from financial or other causes, is as follows:

Auxiliary railways, double track, standard gauge, from Divide Cut east to Greytown, and from Divide Cut west to Ochoa Dam, 20 miles, and telegraph, temporary and permanent systems		$1,110,000
Same on Pacific slope, Rio Lajas to Brito, 18 miles		459,000
		1,569,000
Harbor works:		
Greytown	$2,550,667	
Brito	1,720,128	
		4,270,795
Eastern division:		
Section 1, from Greytown to the Divide		5,298,527
Section 2, the Eastern Divide		18,333,639
Locks Nos. 1, 2, and 3		4,195,828
Diversion of the Deseado and San Juanillo		982,016
San Francisco division		5,411,551
Lake and river division:		
Rio San Juan		3,685,701
Lake Nicaragua		2,211,825
Dam at Ochoa		726,137
Western division:		
From Lake Nicaragua to the Pacific		12,133,849
Diversion of Rio Lajas		346,786
La Flor Dam		577,520
Locks 4, 5, and 6 and guard gates		3,899,116
Right of way indemnity		100,000
Auxiliary work—guard gates in Divide, piers at lake, bridges, etc		1,139,018
Embankments and weirs in the valley of the San Carlos, and canal between Lakes Managua and Nicaragua		1,000,000
Diversion of the Rio Grande		1,035,000
For engineering management, labor agencies, shops, police, sanitary service, and incidentals		6,250,000
		73,166,308
Add to cover specified and unspecified contingencies of construction, 20 per cent		14,633,262
Grand total of estimate		87,799,570

In conclusion, we think it proper to express our opinion that the exploration and studies of the region have been sufficient to warrant the conclusion that, unless hindered by obstacles or sinister influences such as would, if permitted to weigh, forbid the success of all ventures, this enterprise is full of promise.

Respectfully,

JOHN BOGART.
E. T. D. MYERS.
A. M. WELLINGTON.
H. A. HITCHCOCK.

I concur in the foregoing estimates as being in the aggregate ample for the purposes stated.

CHAS. T. HARVEY.

MAY 9, 1889.

APPENDIX M.

SPECIFICATIONS FOR DREDGING REQUIRED IN THE NICARAGUA CANAL AND ITS TERMINAL HARBORS.

The dredging required to be done in the whole canal, including the terminal harbors, the river San Juan and Lake Nicaragua, is divided as follows:

(1) Harbor of San Juan del Norte (Greytown).
(2) Section of canal from San Juan del Norte to Lock No. 1.
(3) River San Juan.
(4) Lake Nicaragua.
(5) Harbor of Brito and section of canal from harbor to Lock No. 6.

(1) HARBOR OF SAN JUAN DEL NORTE (GREYTOWN).

The plan for the restoration of the harbor of San Juan del Norte involves—

(*a*) The construction of a breakwater or jetty, 2,000 feet long, nearly normal to the seashore and extending to the 5-fathom curve.

(*b*) Dredging from this latter depth offshore to and across the sand bank closing the harbor.

(*c*) Dredging in the inner bay.

The jetty is located to windward of the excavated entrance channel, which it is intended to shelter from the sea and protect from the wash of the waves.

The proposed harbor forms a curved oblong figure, with its southern end resting on the entrance to the canal and its northern end, or sea entrance, contracted to a narrow throat just outside of the beach, and then enlarged again to the 5-fathom curve.

At the extreme north end of the excavation, or 5-fathom curve, the excavated channel will have a width of 1,400 feet. This width gradually decreases toward the narrowest part, or throat, which is 500 feet wide at a point 1,450 feet distant from the 5-fathom curve, where the excavation begins. From this narrow entrance to the shore line the distance is 350 feet, and across the sand bank from the seashore line to the water line in the inner bay about 250 feet, making a total distance of about 2,050 feet from the 5-fathom line to the shore line in the inner bay.

The distance across the inner bay along the sailing line or axis of the harbor, from shore to shore, is 3,750 feet.

The width of the harbor where it crosses the present southern shore line of Greytown Lagoon is 1,300 feet, and the length of the extension of the harbor southwesterly from this line is 2,400 feet to the end of the regular canal section.

The maximum width of the excavated channel is 2,800 feet on the bottom and the total length from the 5-fathom line to the canal entrance is 8,200 feet.

All slopes are assumed outside of beach line as 6 horizontal to 1 vertical, and inside as 3 to 1, extending from the bottom of the excavated basin to the natural bottom or to the surface of the ground.

The borings taken show the material to be removed to consist of sand, offshore and across the beach or sand bank, and sand with a slight mixture of clay in the inner bay. The contractor, however, is expected to examine and decide for himself, as no allowance will be made should any of it prove to be of a different kind. The total amount of material to be removed, measured in place, is about 9,550,000 cubic yards, divided as follows:

	Cubic yards.
Excavation from 5-fathom curve to seashore line	824,500
Excavation from shore line to shore line across beach	195,300
Excavation in inner bay to south shore of lagoon	6,748,700
Excavation from south shore of lagoon to canal entrance	1,781,500
Total	9,550,000

These quantities are only approximate, due to the constant shifting of the sand offshore, and may be increased or diminished as the conditions may require. All material to be removed will be measured in place from careful surveys and cross sections made before and after dredging, and will be paid for by the cubic yard. The contractor shall have the right of verifying the measurements, and the decision of the chief engineer as to the amount of material excavated and deposited shall be final.

A margin of 1 foot in excess of the depth stipulated will be allowed and paid for.

All shoals, lumps, or ridges left by the dredges must be removed.

All the material excavated must be deposited on the lowlands in the vicinity of the harbor, on the pier or jetty at the entrance or east of that jetty, or at sea, north of the harbor and at depths not less than 12 fathoms.

In case the material be put ashore through pipes by any hydraulic process, all embankments, fences, drains, or any other work needed for confining the material and preventing its sliding into the excavated channels, or for draining the banks, must be provided for and paid for by the contractor.

It is estimated that not less than 1,000,000 cubic yards will be needed in connection with the construction of the jetty or pier, and the contractor must deposit this material at such time and at such places as the chief engineer may designate. All dumping grounds must be selected by the chief engineer.

The limit of dredging will be staked out by the company, and any dredging done outside these limits will not be paid for.

All stakes and tide gauges must be furnished by the contractor, under the direction of the engineer in charge of the work, and the cost of the same, together with that of the boats and men for setting them up, is to be included in the price of dredging.

The work is to be carried on at such points and in such order of precedence as may be directed by the engineer.

Any doubt as to the meaning of these specifications and any obscurity in the wording of them will be explained by the chief engineer, who shall have the right to correct any errors or omissions in them when such correction is necessary for the proper fulfillment of their intentions.

No claims for extra work or for delay of any kind will be considered or paid unless an agreement therefor shall be made in writing and approved by the company. The contract price is to be full compensation for furnishing all the materals, labor, and appliances necessary and for all the work herein specified, including the removal of any logs or snags which may be encountered.

All machinery to be used must be of approved make, kept in good repair, and the whole apparatus maintained in good working order at all times. Scows, if used, must be sound and tight and of a draft adapted to the work.

Inspectors shall be appointed by the chief engineer to see that the tide gauges, stakes, etc., are kept in proper order and to enforce a strict compliance with the terms of the contract. The contractor shall furnish each inspector with subsistence when he is on duty and with such facilities as are necessary for the proper execution of his duties without extra charge.

Bidders will state in their proposals the time when the work shall be commenced, the amount to be done monthly, and the time when the work will be completed.

(2) SECTION OF CANAL FROM THE HARBOR OF SAN JUAN DEL NORTE (GREYTOWN) TO LOCK NO. 1 OF THE CANAL.

This section of the canal is about 9½ miles long, and is to be excavated to a uniform depth of 28 feet below the level of low tide at Greytown. The channel will have a uniform width at the bottom of 120 feet and slopes of 3 horizontal to 1 vertical extending from the bottom of the excavation to the surface of the ground or bottom of wet swamps or lagoons. A margin of 1 foot in excess of that designated to be made will be allowed. Dredging below a depth of 1 foot in excess of that designated will not be paid for.

All shoals, lumps, or ridges left by the dredge must be removed.

The elevation of the ground varies at every point along the line from 1 to several feet above or below sea level.

The material to be excavated is believed to be mud, loam, sand, and clay. Each bidder, however, is expected to examine the ground and decide for himself, as no allowance will be made should any prove to be of a different kind, except that solid rock and large bowlders will not have to be removed. No buried logs have been discovered by the borings, but if any are found they shall be removed by the contractor without extra charge.

All excavated material must be deposited on the sides of the excavation and not less than 195 feet from the axis of the canal, and all embankments, bulkheads, fences, or whatever else may be needed for confining the material beyond the limit specified (195 feet from the axis of the canal), must be maintained at the contractor's expense. All material deposited inside of that limit will not be paid for, it being understood that in no case the excavated material will be allowed to be deposited at a distance of less than 25 feet from the crest of the slopes of the canal prism as staked out by the engineer in charge. The contractor will also be required to provide for draining off the water, and must deposit the material as required by the chief engineer so as to facilitate drainage.

The estimated amount of material to be removed in these 9½ miles of canal is about 13,550,000 cubic yards, but the amount is approximate only, and may be increased or diminished.

The company reserve the right to change the location of all or any portion of the line without affecting the contract price, provided the conditions as to the nature of the material and general character of the work remain the same.

The dredging or excavation will be paid for by the cubic yard, and will be measured, in place, by cross sections taken before and after dredging.

The measurements will be made, as the work advances, in sections of 400 feet in length, these sections to be not less than 200 feet in the rear of the dredge.

Any filling that may take place as the result of sliding of the banks to a flatter slope than 3 horizontal to 1 vertical, after acceptance of a section, if required to be removed by dredging, shall be removed by the contractor and paid for at contract price.

Any material sliding into the excavation from the deposited bank shall be removed by the contractor without charge.

The contractor, in his proposal, shall describe fully his method of depositing material on the sides of the excavation, and he must satisfy the chief engineer that his method is adapted to the work.

All machinery to be used must be of approved make, kept in good repair, and the whole apparatus maintained in sound working order at all times.

The limits of dredging will be staked out by the company, and any dredging done outside those limits will not be paid for.

All stakes and tide gauges must be furnished by the contractor, under the direction of the engineer in charge of the work, and the cost of the same, together with that of the boats and men for setting them up, is to be included in the price of dredging.

Inspectors shall be appointed by the chief engineer to see that the tide gauges, stakes, etc., are kept in proper order, and to enforce a strict compliance with the terms of the contract. The contractor shall furnish each inspector, when he is on duty, with such facilities as are necessary for the proper execution of his duties without extra charge.

The work is to be carried on at such points and in such order of precedence as may be directed by the chief engineer.

Any doubt as to the meaning of these specifications and any obscurity in the wording of them will be explained by the chief engineer, who shall have the right to correct any errors or omissions in them when such correction is necessary for the proper fulfillment of their intention.

No claims for extra work or for delay of any kind will be considered or paid for unless an agreement therefor shall be made in writing and approved by the company. The contract price is to be full compensation for furnishing all the materials, labor, and appliances necessary and for doing all the work herein specified, including the removal of any logs or snags which may be encountered.

Bidders will state in their proposals the time when the work shall be commenced, the amount to be done monthly, and the time when the work will be completed.

(3) RIVER SAN JUAN.

The dredging required in the river San Juan is comprised between the river Savalos and Lake Nicaragua, a distance of about 28 miles by the course of the river. It will consist in deepening and widening the river channel, the depth to be made to be 28 feet below the level of the water in Lake Nicaragua when raised to 110 feet above the mean level of the sea, and the width to be 125 feet at the bottom of the excavated channel within such limits as the chief engineer may designate.

A margin of 1 foot in excess of that designated will be allowed. Dredging below a depth of 1 foot in excess of that designated to be made will not be paid for.

All shoals, lumps, or ridges left by the dredge must be removed. The depth of the excavation varies at the different places of dredging.

The material to be removed is believed to be mud, sand, clay, gravel, and loose stones. Each bidder, however, is expected to examine and decide for himself, as no allowance will be made should any of it prove to be of a different kind, except that solid rock and large bowlders will not have to be removed.

All the excavated material must be deposited on the banks of the river or in such places in the river as the chief engineer may designate.

The contractor, in his proposal, will describe fully his method of depositing the material on the banks or in the river channel, as he may be directed, and he must satisfy the chief engineer that his method is adapted to the work.

In case the material be put ashore through pipes by any hydraulic process, all embankments, fences, bulkheads, etc., needed for confining the material and permitting the water to run off must be made at the contractor's expense. The contractor must also provide all necessary drains and deposit the material as required by the engineer so as to facilitate drainage and prevent the material sliding back into the river channel. Scows, if used, must be sound and tight and of a draft adapted to the work.

The estimated amount of dredging to be done is about 2,150,000 cubic yards. This amount is approximate only, and may be increased or diminished.

The dredging will be paid for by the cubic yard, and will be measured in place (in the river) by cross sections taken before and after dredging. The measurements will be made and the work accepted in sections of about 400 feet in length, measured not less than 200 feet back from the rear of the dredge.

The decision of the engineer in charge as to the amount of material excavated and deposited shall be final.

The limits of dredging will be staked out by the company, and any dredging done outside those limits will not be paid for.

All stakes and tide guages must be furnished by the contractor under the direction of the engineer in charge of the work, and the cost of the same, together with that of the boats and men for setting them up, is to be included in the price of dredging.

Inspectors shall be appointed by the chief engineer to see that the tide gauges, stakes, etc., are kept in proper order, and to enforce a strict compliance with the terms of the contract. The contractor shall furnish each inspector with subsistence when he is on duty, and with such facilities as are necessary for the proper execution of his duties, without extra charge.

The work is to be carried on at such points and in such order of precedence as the engineer in charge may direct.

Any doubt as to the meaning of these specifications and any obscurity in the wording of them will be explained by the engineer in charge, who shall have the right to correct any errors or omissions in them when such correction is necessary for the proper fulfillment of their intention.

No claims for extra work or for delay of any kind will be considered or paid for unless an agreement therefor shall be made in writing and approved by the company. The contract price is to be full compensation for furnishing all the materials, labor, and appliances necessary and for doing all the work herein specified, including the removal of any logs or snags which may be encountered.

All machinery to be used must be of approved make, kept in good repair, and the whole apparatus maintained in sound working order at all times.

Bidders will state in their proposals the time when the work shall be commenced, the amount to be done monthly, and the time when the work will be completed.

(4) LAKE NICARAGUA.

The dredging required at the east side of Lake Nicaragua extends from Fort San Carlos, at the outlet of the lake, about 72,500 feet, or 13.50 miles, west to the depth of 30 feet, when the water in the lake stands at 110 feet above mean level of the sea. It will consist in excavating a channel along that distance, the depth to be made to be 30 feet below the level of the water when raised 110 feet above mean sea level, and the width at the bottom of the excavated channel to be 150 feet.

The slopes of the proposed channel are assumed as 3 horizontal to 1 vertical, extending from the bottom of the excavated channel to the bottom of the lake.

A margin of 1 foot in depth in excess of that designated will be allowed. Dredging below a depth of 1 foot in excess of that designated will not be paid for.

All shoals, lumps, or ridges left by the dredge must be removed.

The depth of the excavation varies at different places along the length of the channel. The average depth of the cut to 30 feet depth is about 9.8 feet and the greatest depth is about 17.3 feet.

In case the excavated channel assumes a natural slope flatter than 3 to 1, as herein specified, the filling that may take place as the result of sliding of the banks, if required to be removed, shall be done by the contractor and will be paid for at contract price.

Any material sliding into the excavated channel from the deposited bank shall be removed by the contractor without charge.

The material to be excavated is believed to be mud, sand, and clay. Each bidder is expected, however, to examine and decide for himself, as no allowance will be made should any of it prove to be of a different kind, except that solid rock and large bowlders will not have to be removed.

All the excavated material must be deposited in the lake in such places as the chief engineer may designate.

The contractor, in his proposal, will describe fully his method of depositing the material, and he must satisfy the chief engineer that his method is adapted to the work.

No material will be allowed to be deposited at any point distant less than 1,500 feet from the axis of the channel.

In case the material be deposited through pipes by any hydraulic process, the contractor must provide the necessary means to prevent its being washed back into the channel. Scows, if used, must be sound and tight and of a draft adapted to the work.

The estimated amount of dredging to be done is about 4,726,000 cubic yards. This amount is approximate only, and may be increased or diminished.

The dredging will be paid for by the cubic yard, and will be measured in place (in the lake) by cross sections taken before and after dredging. The measurements will be made and the work accepted in sections of about 400 feet in length and measured not less than 200 feet back from the rear of the dredge.

The decision of the engineer in charge, as to the amount of material excavated and deposited, shall be final.

The limits of dredging will be staked out by the company, and any dredging done outside these limits will not be paid for.

All stakes and tide gauges must be furnished by the contractor, under the direction of the engineer in charge of the work, and the cost of same, together with that of the boats and men for setting them up, is to be included in the price of dredging.

Inspectors shall be appointed by the chief engineer to see that the tide gauges, stakes, etc., are kept in proper order and to enforce a strict compliance with the terms of the contract. The contractor shall furnish each inspector with subsistence when he is on duty, and with such facilities as are necessary for the proper execution of his duties, without extra charge.

The work is to be carried on at such points and in such order of precedence as the engineer in charge may direct.

Any doubt as to the meaning of these specifications and any obscurity in the wording of them will be explained by the chief engineer, who shall have the right to correct any errors or omissions in them, when such correction is necessary for the proper fulfillment of their intentions.

No claims for extra work or for delay of any kind will be considered or paid for unless an agreement therefor shall be made in writing and approved by the company. The contract price is to be full compensation for furnishing all the material, labor, and appliances necessary for doing all the work herein specified, including the removal of any logs or snags which may be encountered.

All machinery to be used must be of approved make, kept in good repair, and the whole apparatus maintained in sound working order at all times.

Bidders will state in their proposals the time when the work shall be commenced, the amount to be done monthly, and the time when the work will be completed.

(5) HARBOR OF BRITO.

The plans for the creation of a harbor at Brito involve the construction of two breakwaters or jetties, one projecting from the promontory west of the entrance and the other nearly normal to the coast line to the east of the proposed entrance, and dredging in the valley of the Rio Grande, extending to the beach at that point.

The dredging extends for a distance of 6,700 feet from the 5-fathom line to Lock No. 6 of the canal, which is regarded as the inner end of the harbor. This total distance is divided as follows:

	Feet.
From the 5-fathom curve to low-water line	700
From low-water line to end of main harbor	3,000
From this latter point to Lock No. 6	3,000

The dredging will consist in excavating a basin, as shown in the plans of the harbor, and its extension to Lock No. 6, the depth to be made to be 30 feet below low water in the Pacific throughout, and the width at the bottom of the excavated channel in the extension from the basin to Lock No. 6 to be 120 feet.

The slopes of the proposed channel and basin are assumed as 3 horizontal to 1 vertical, extending from the bottom of the excavation to the bottom of the sea or to the natural surface of the ground. A margin of 1 foot in depth in excess of that designated will be allowed. Dredging below a depth of 1 foot in excess of that designated will not be paid for.

All shoals, lumps, or ridges left by the dredge must be removed.

In case the excavated channel assumes a natural slope flatter than 3 to 1, as herein specified, the filling that may take place as the result of slidings of the banks, if required to be removed, will be paid for at contract price.

All the excavated material must be deposited at sea or ashore at such places as the chief engineer may designate.

The contractor will describe fully the method of depositing the material, and he must satisfy the engineer that his method is adapted to the work.

No material will be allowed to be deposited at any point distant less than 200 feet from the foot of the slope in the excavated channel or basin. In case the material is deposited through pipes by any hydraulic process, the contractor must provide the necessary means to prevent its being washed into the channel or basin. Scows, if used, must be sound and tight and of a draft adapted to the work.

The borings taken show the material to be removed to consist of sand, or sand and mud, and mud in the swamps. The contractor, however, is expected to examine and decide for himself, as no allowance will be made should any of it prove to be of a different kind, except that solid rock and large bowlders will not have to be removed.

The amount of material to be removed, measured in place, is about 6,700,000 cubic yards, more or less, divided as follows:

	Cubic yards.
From 5-fathom line to low-water line	860,580
From low-water line to end of basin	4,798,318
From end of basin to Lock No. 6	1,066,666
Total	6,725,564

This amount is approximate only, and may be increased or diminished.

The dredging will be paid for by the cubic yard, and will be measured in place (in the harbor) by cross section taken before and after dredging. The measurements will be made and the work accepted in sections of about 400 feet in length and not less than 200 feet from the rear of the dredge.

The decision of the engineer in charge as to the amount of material excavated and deposited shall be final.

The limit of dredging shall be staked out by the company, and any dredging done outside those limits will not be paid for.

All stakes and tide gauges must be furnished by the contractor, under the direction of the engineer in charge of the work, and the cost of the same, together with that of the boats and men for setting them up, is to be included in the price of dredging.

Inspectors shall be appointed by the chief engineer to see that the tide gauges, stakes, etc., are kept in proper order and to enforce a strict compliance with the terms of the contract. The contractor shall furnish each inspector with subsistence when he is on duty, and with such facilities as are necessary for the proper execution of his duties, without extra charge.

The company reserves the right to change the design of the harbor and thereby increase or diminish the amount of material excavated. In case of increase, the contract price will be paid for the additional work; provided, however, that the change in plan does not change the general character of the material to be excavated.

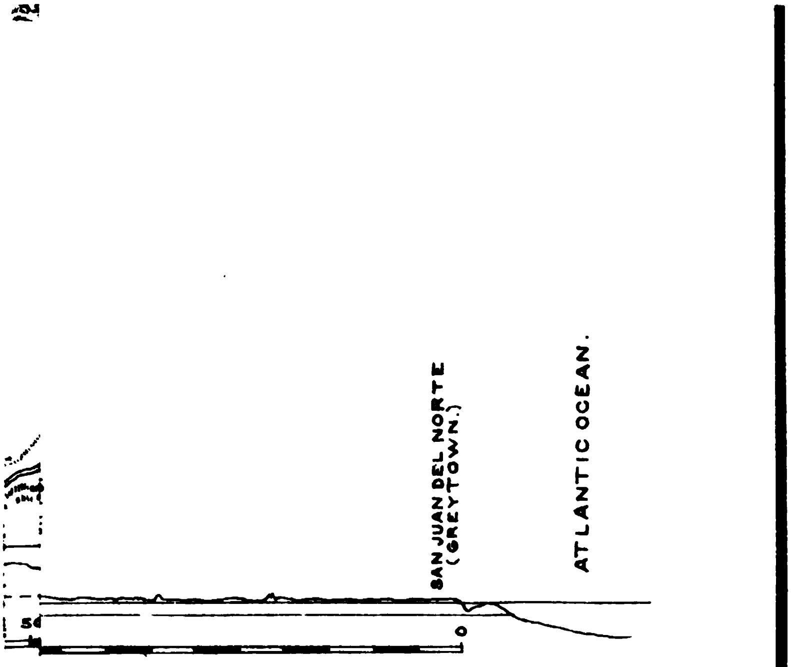
The work is to be carried on at such points and in such order of precedence as the engineer in charge may direct.

Any doubt as to the meaning of these specifications and any obscurity in the wording of them will be explained by the chief engineer, who shall have the right to correct any errors or omissions in them when such corrections are necessary for the proper fulfillment of their intentions.

No claim for extra work or for delay of any kind will be considered or paid for unless an agreement therefor shall be made in writing and approved by the company. The contract price is to be full compensation for furnishing all the material, labor, and appliances necessary for doing all the work herein specified, including the removal of any logs or snags which may be encountered.

All the machinery to be used must be of approved make, kept in good repair, and the whole apparatus maintained in sound working order at all times.

Bidders will state in their proposals the time when the work shall be commenced, the amount to be done monthly, and the time when the work will be completed.



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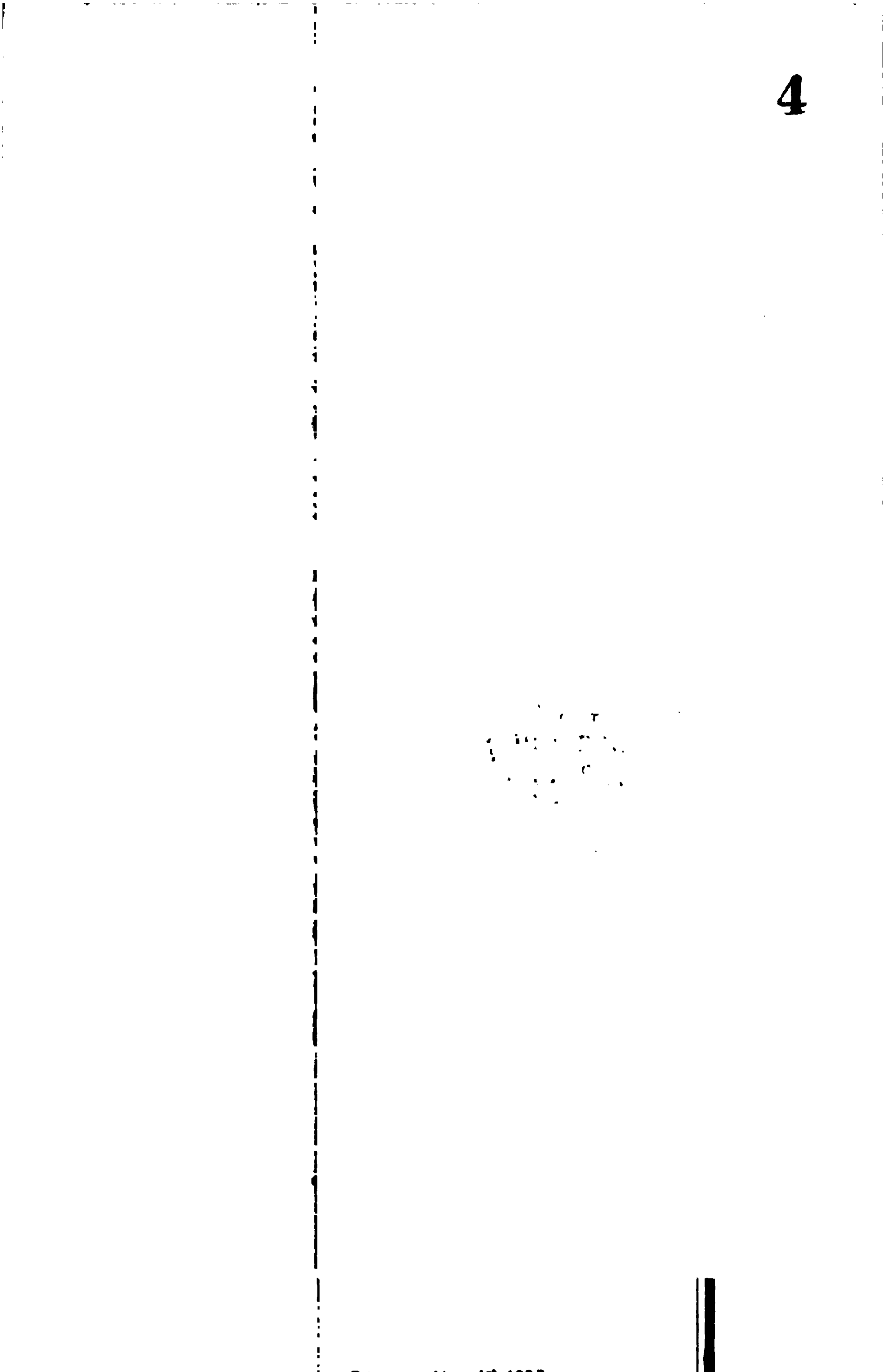

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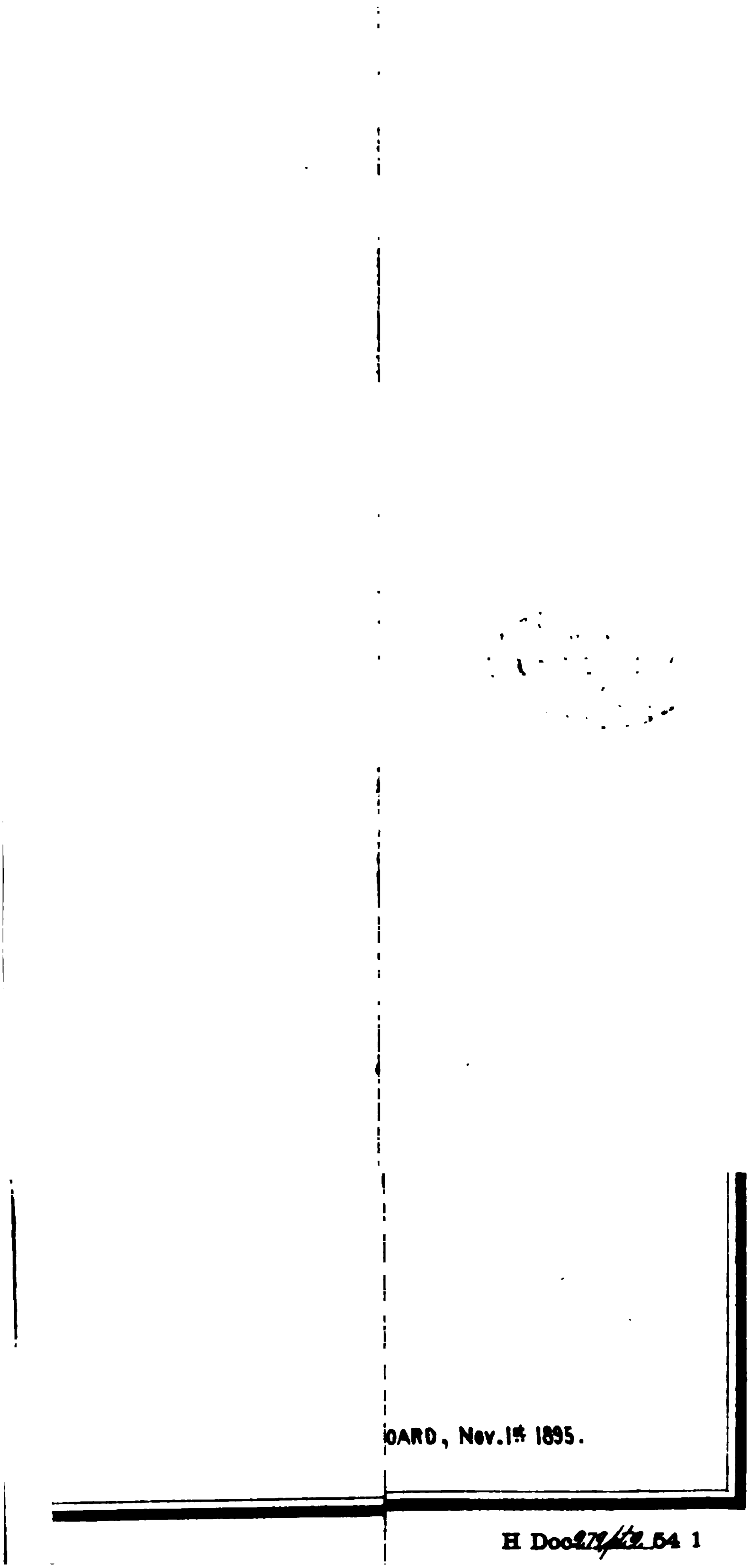
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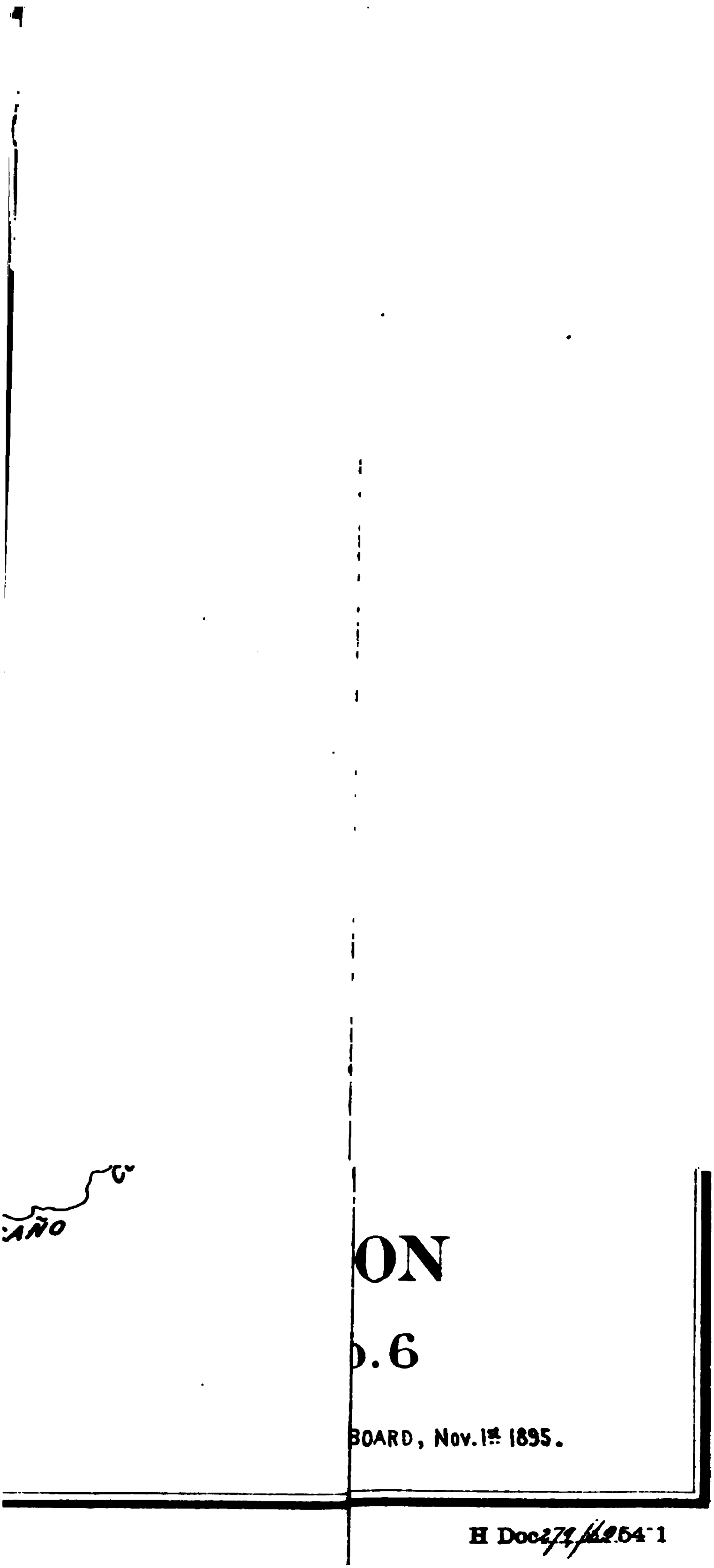

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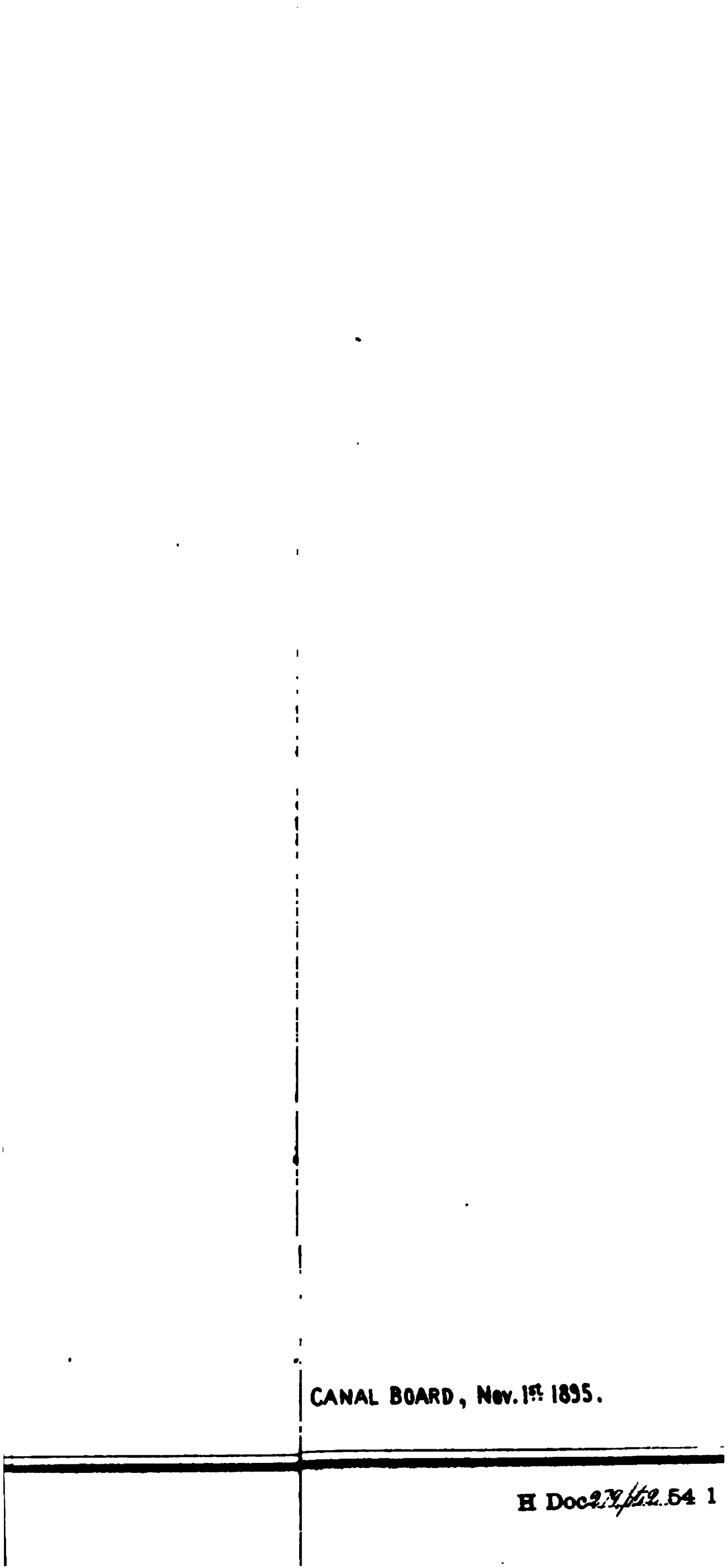

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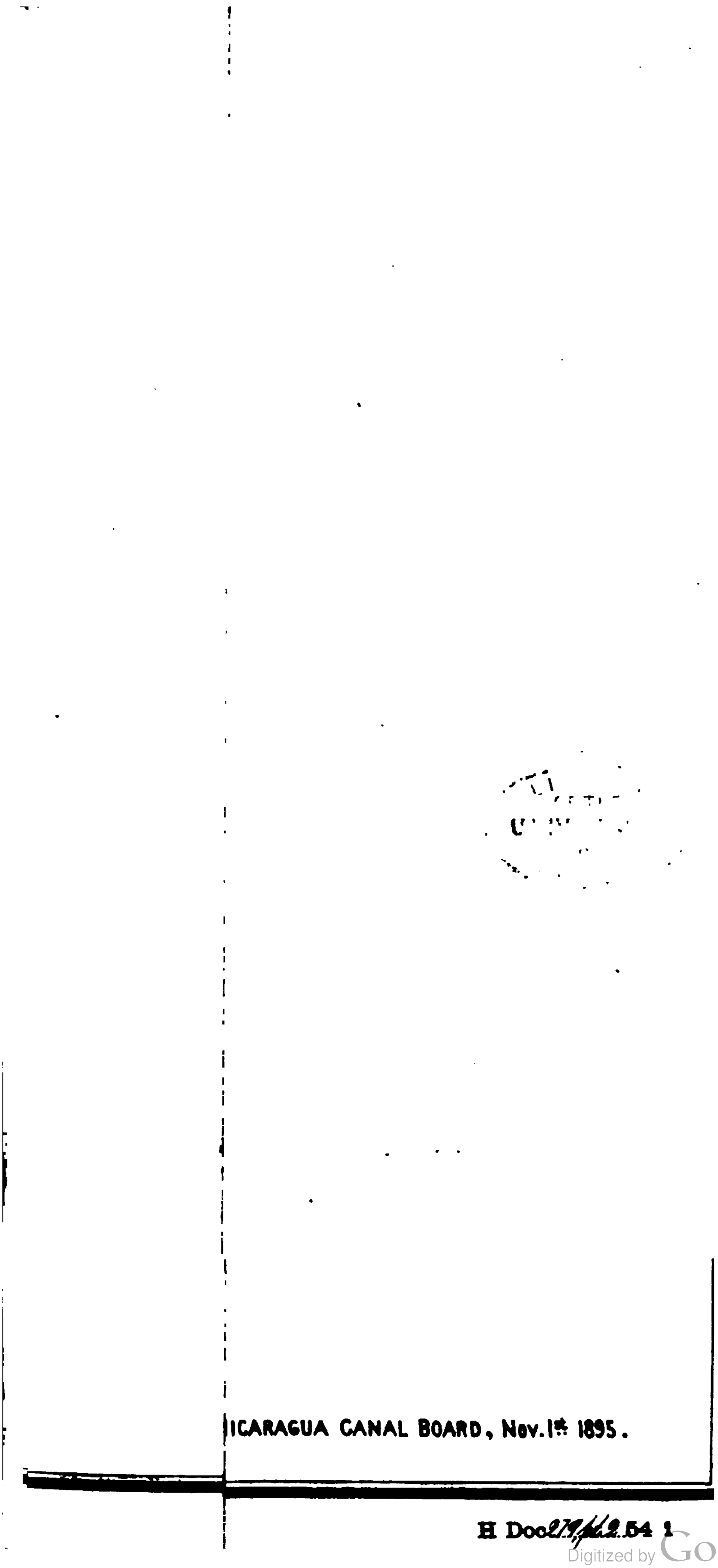

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PLATE X.

PLATE XI.

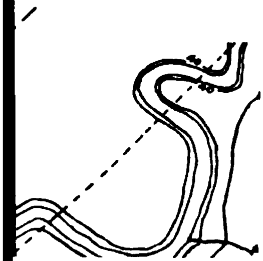

PLATE XII.

PLATE XIII.

PLATE XIV.

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PLATE XV.

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PLATE XVI.

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PLATE XVII.

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PLATE XIX.

PLATE XX .

'A CANAL BOARD, Nov. 1st 1895.

H Doc 279, pt. 2, 54 1

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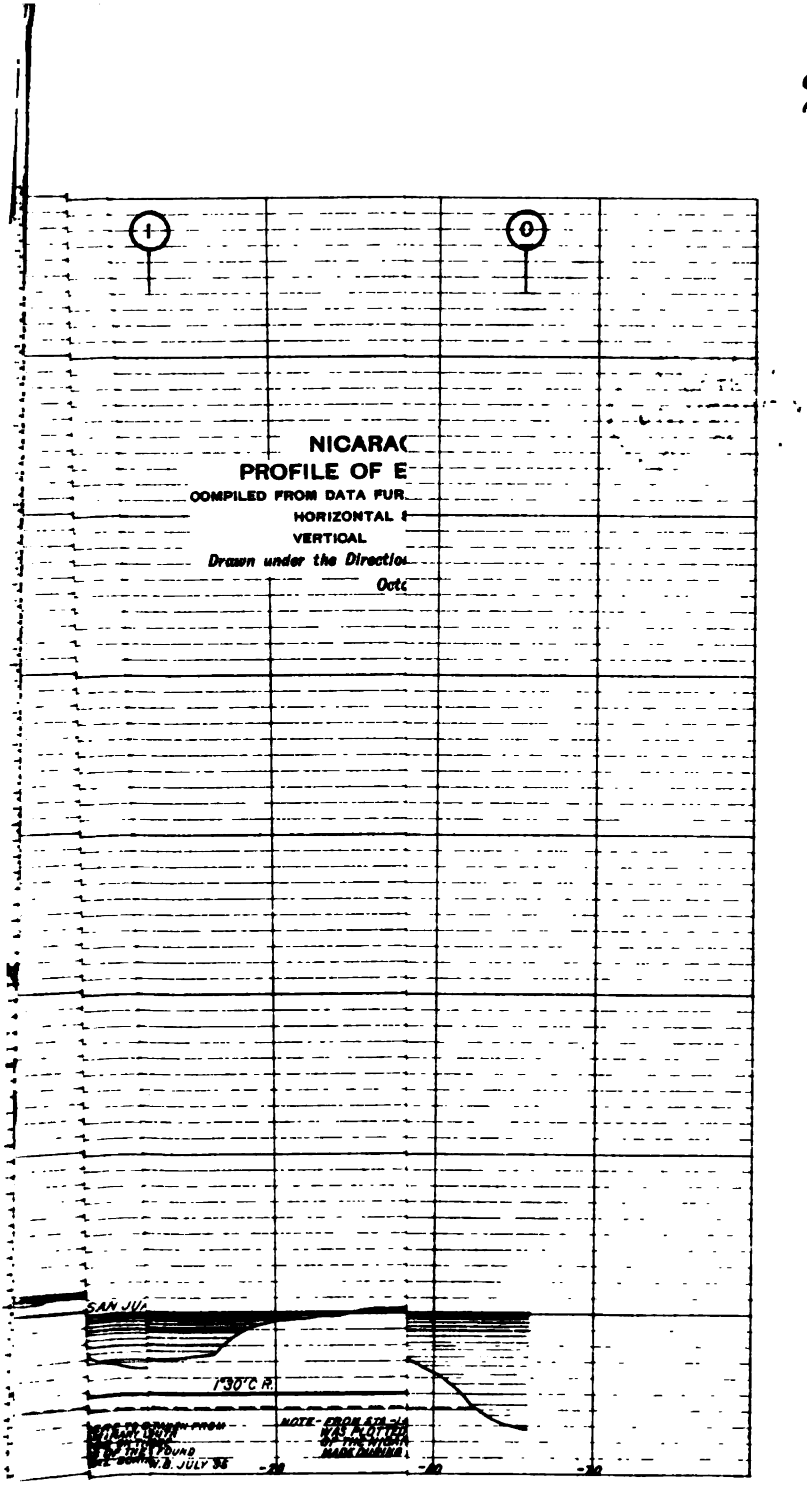
Nov. 1st 1895.

ANAL BOARD, NOV. 1st 1895.



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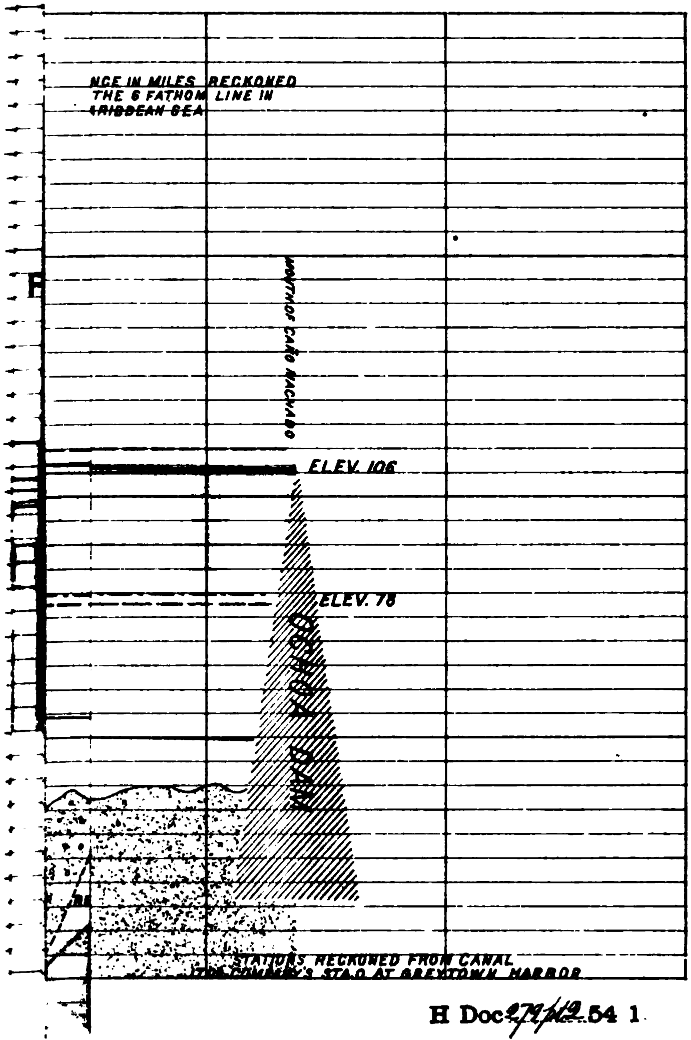

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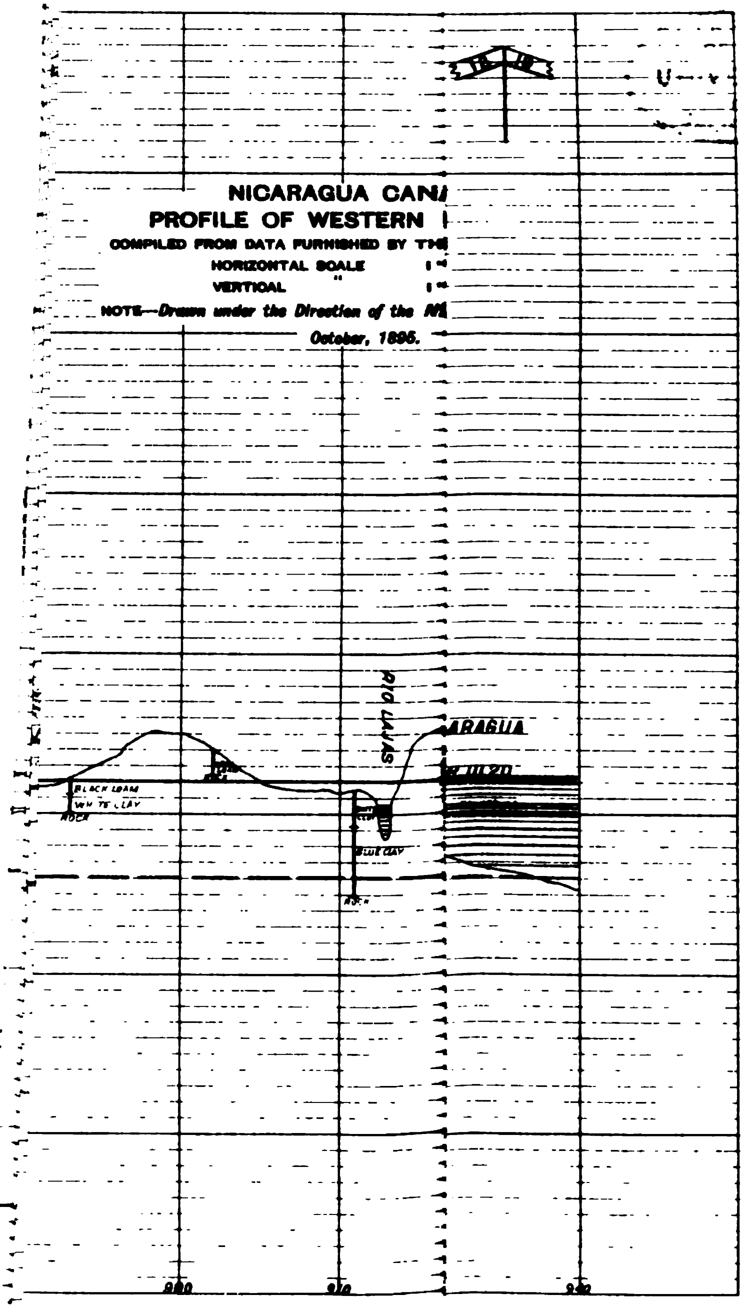

NICARAGUA CAN
PROFILE OF WESTERN
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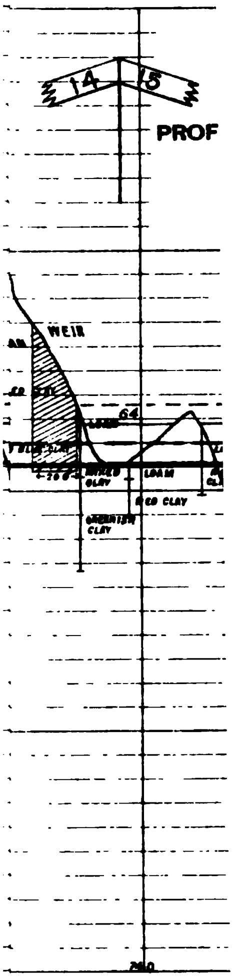
October, 1895.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BLUE CLAY
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RED CLAY
GREENISH CLAY
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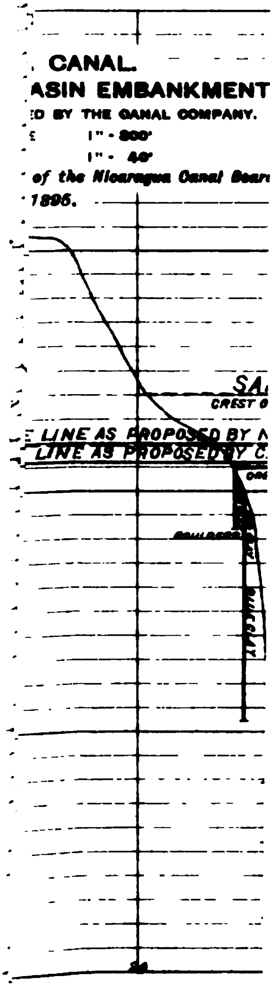
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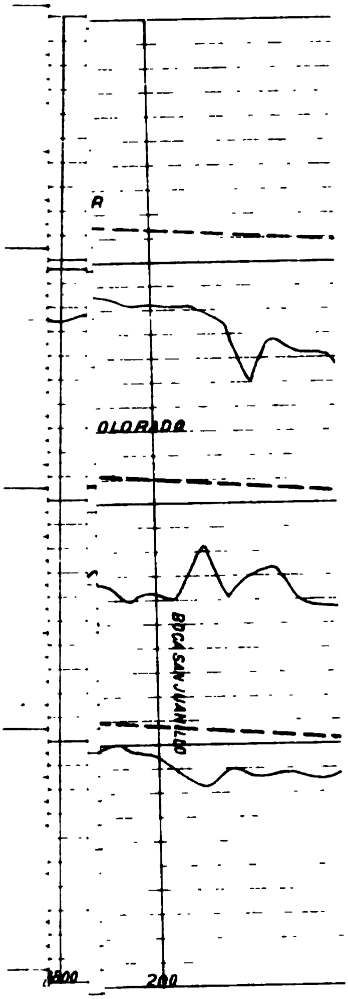
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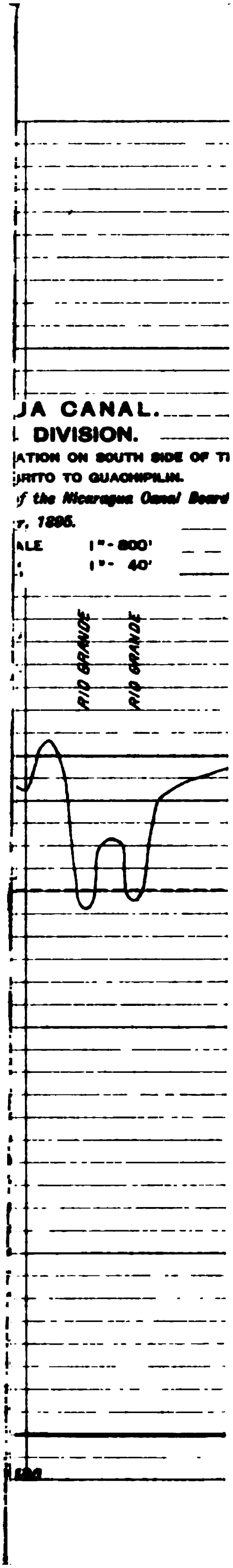
JA CANAL.
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f the Nicaragua Canal Board
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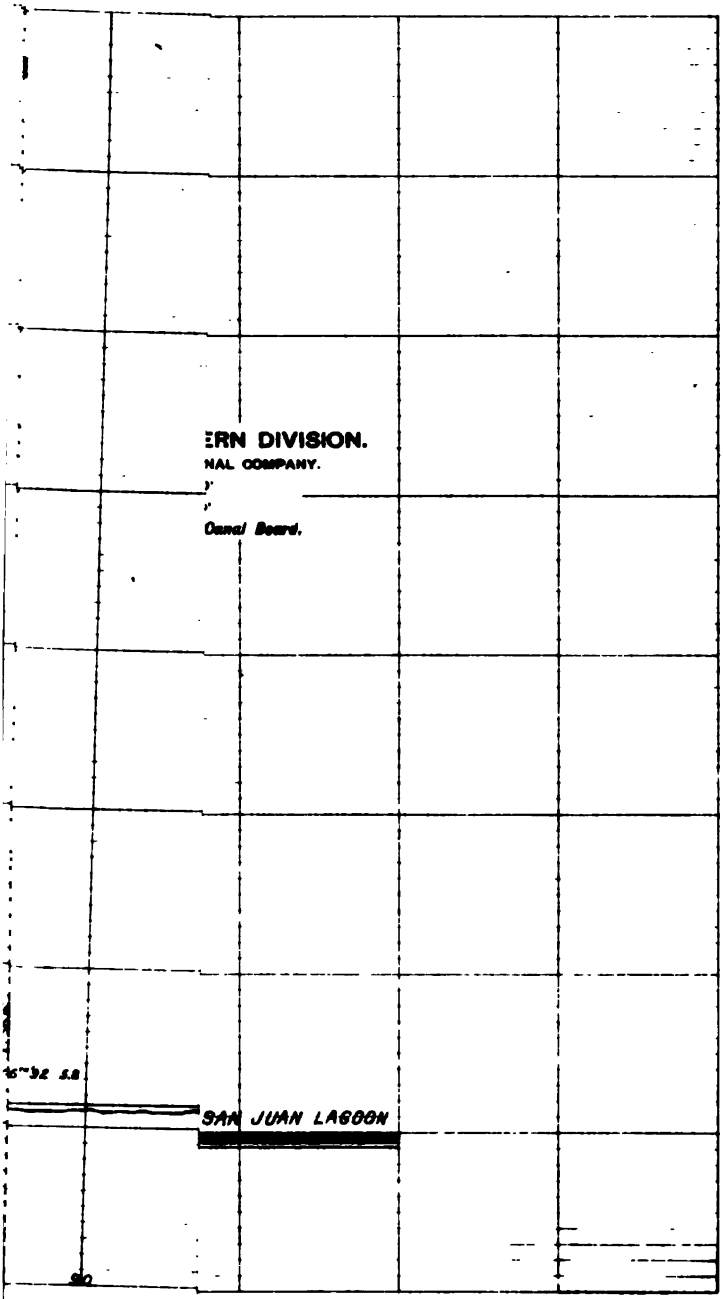
RIO GRANDE



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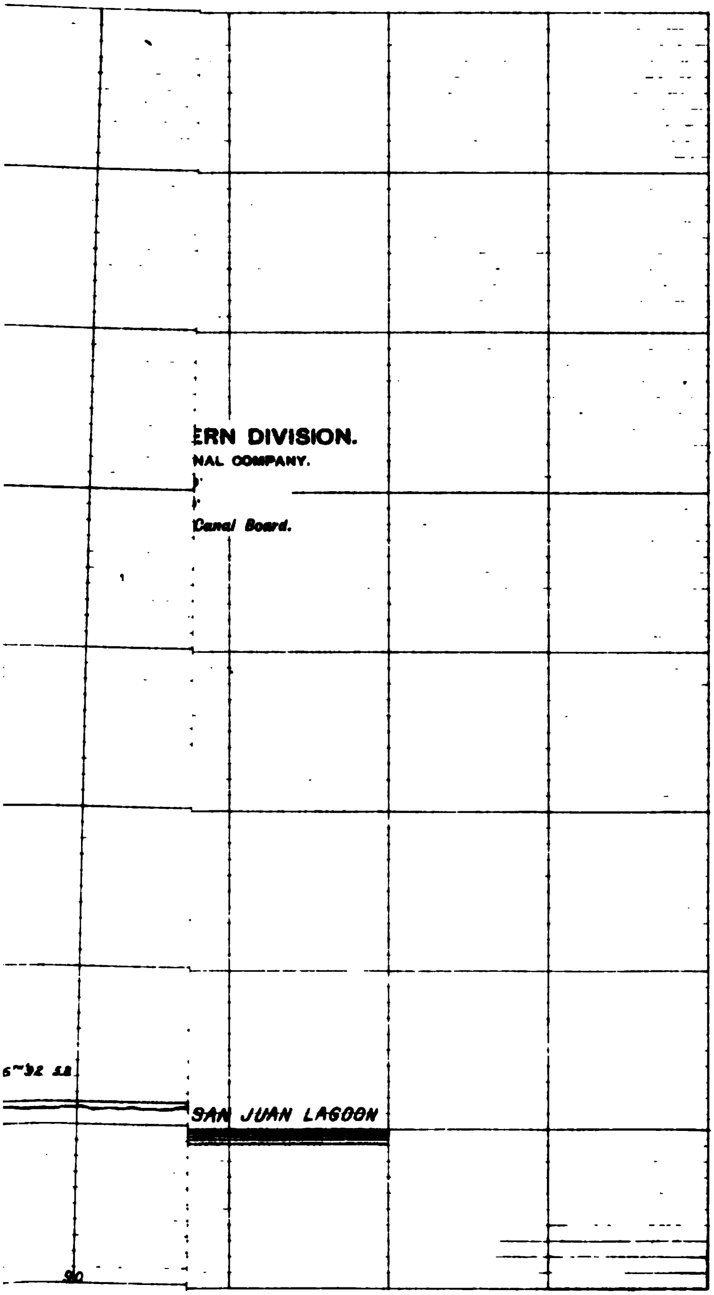

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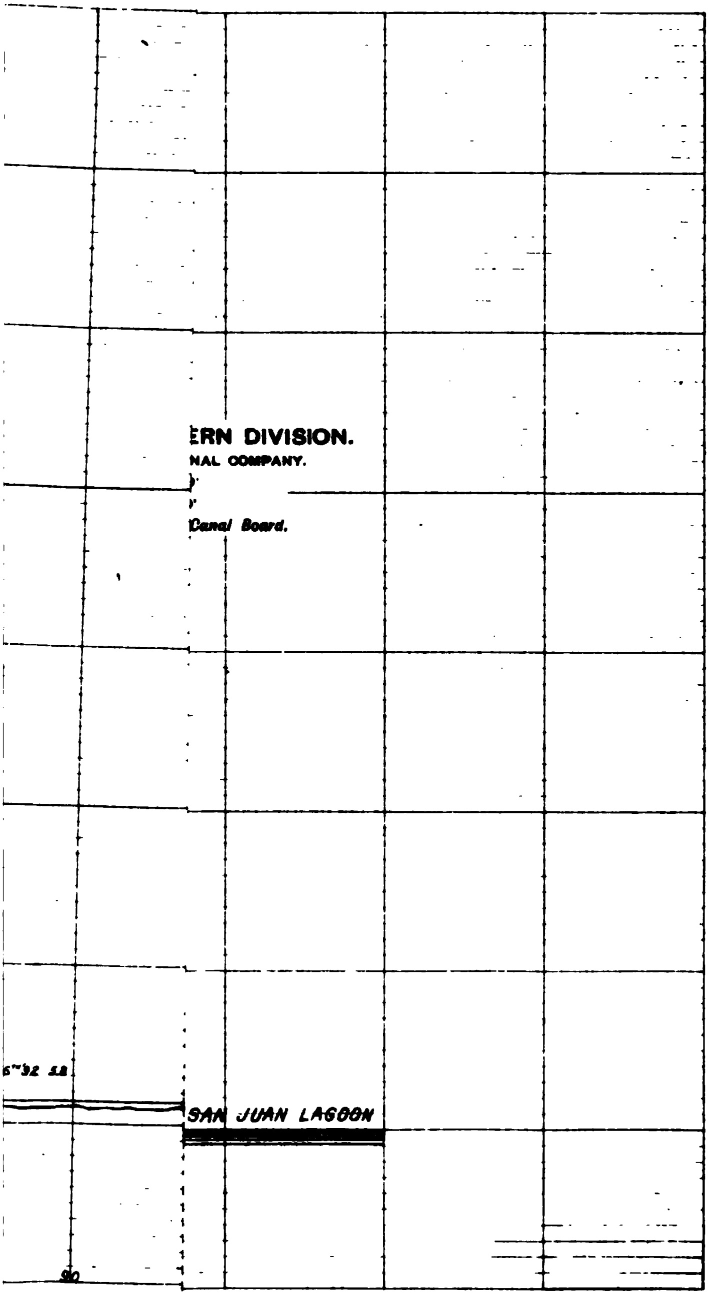

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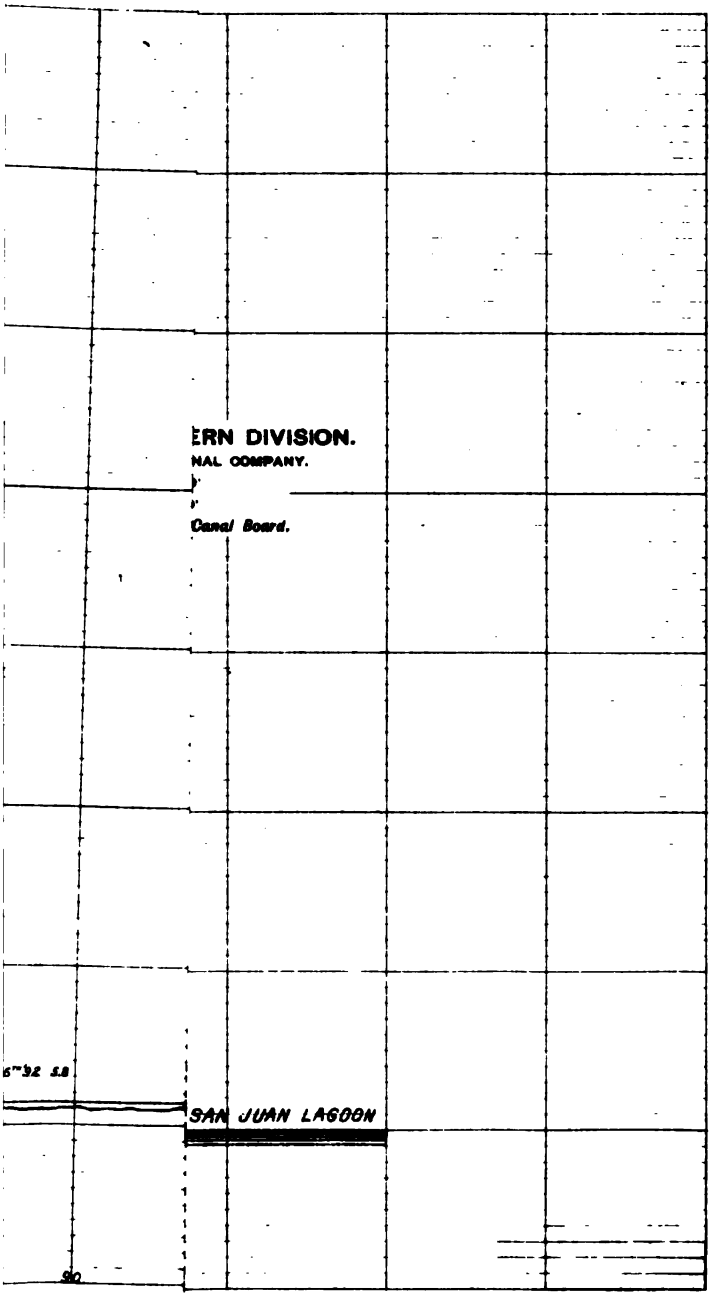

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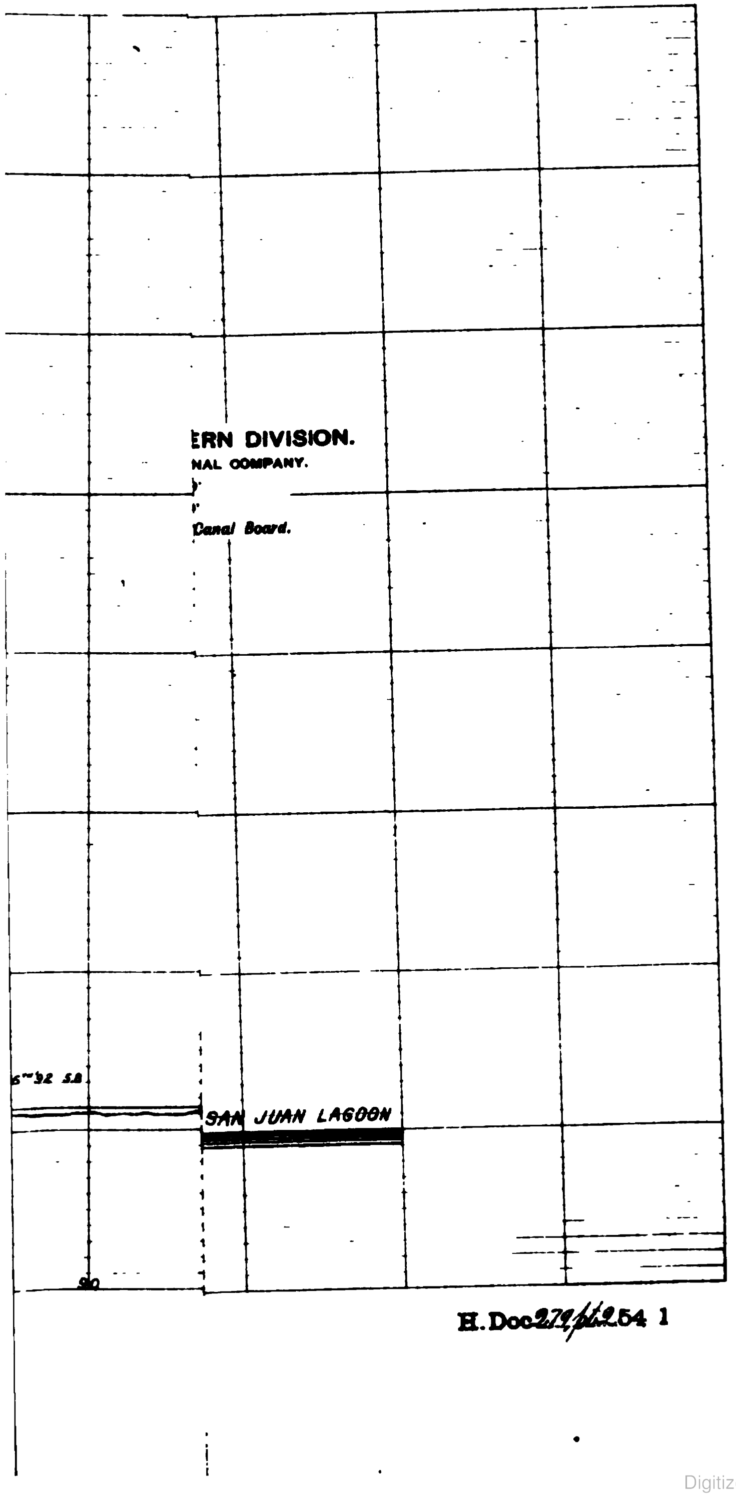

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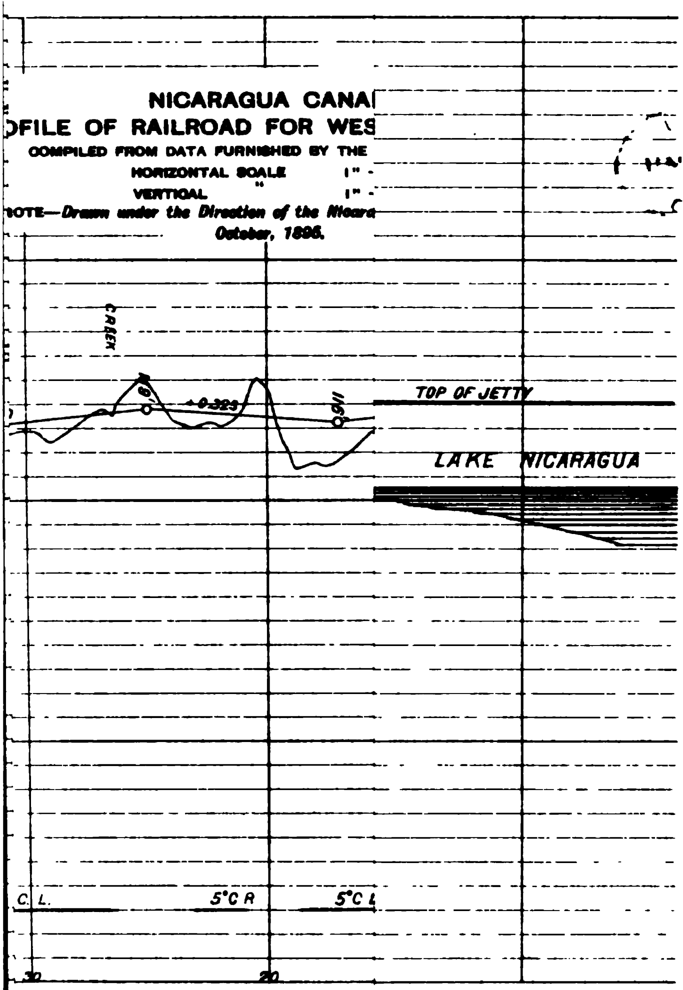
NICARAGUA CANA
FILE OF RAILROAD FOR WES
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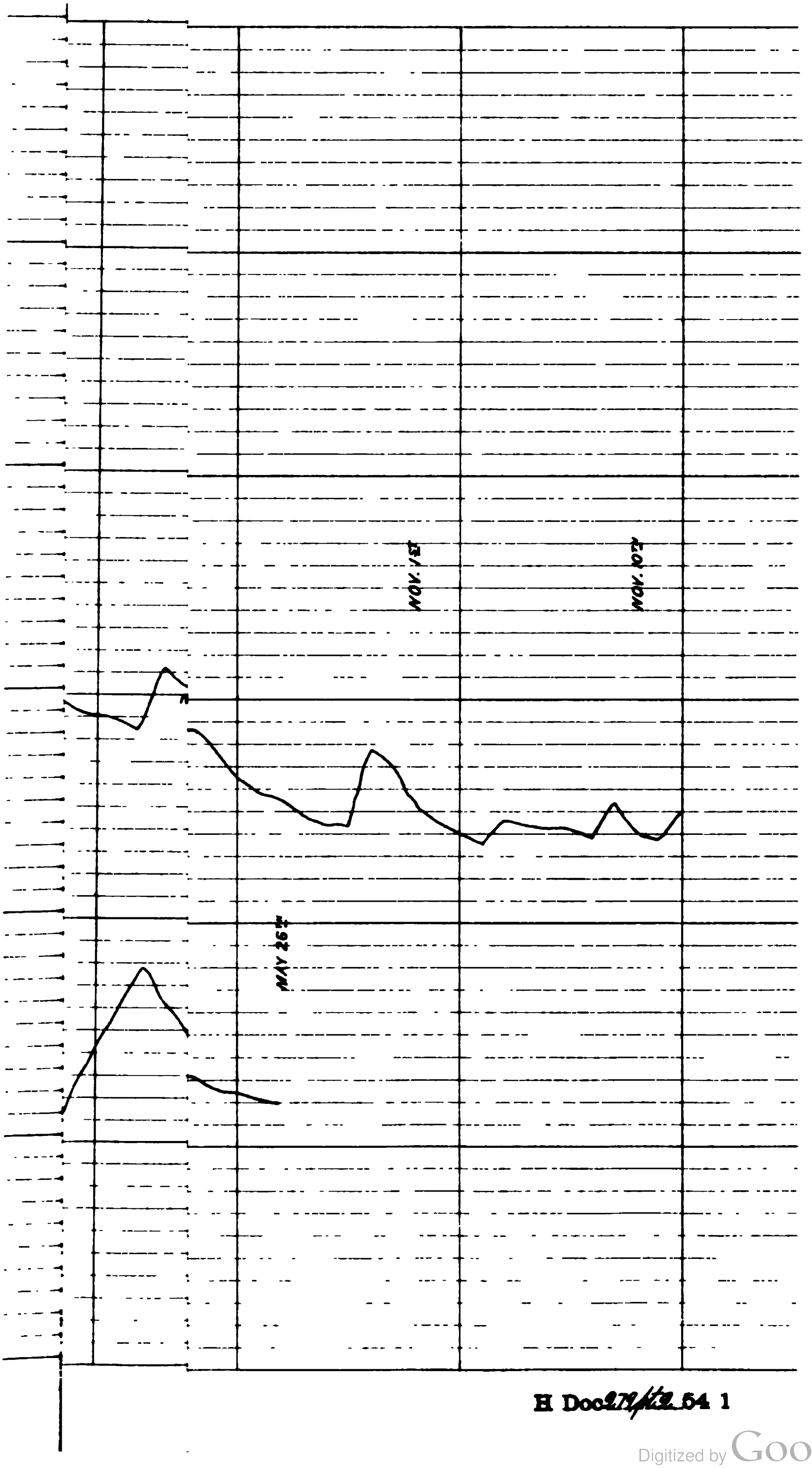
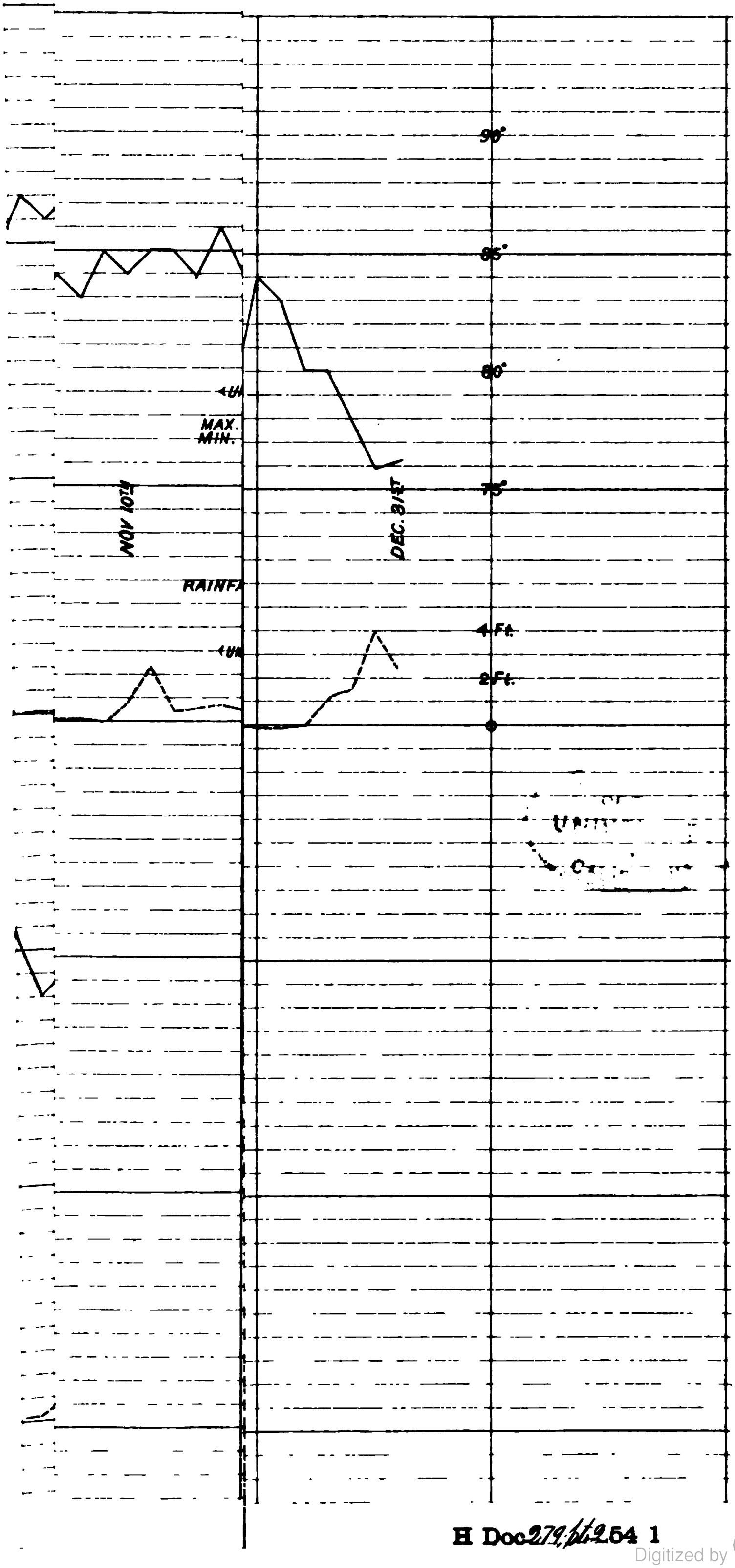

NOV. 1st
NOV. 10th
MAY 26th



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